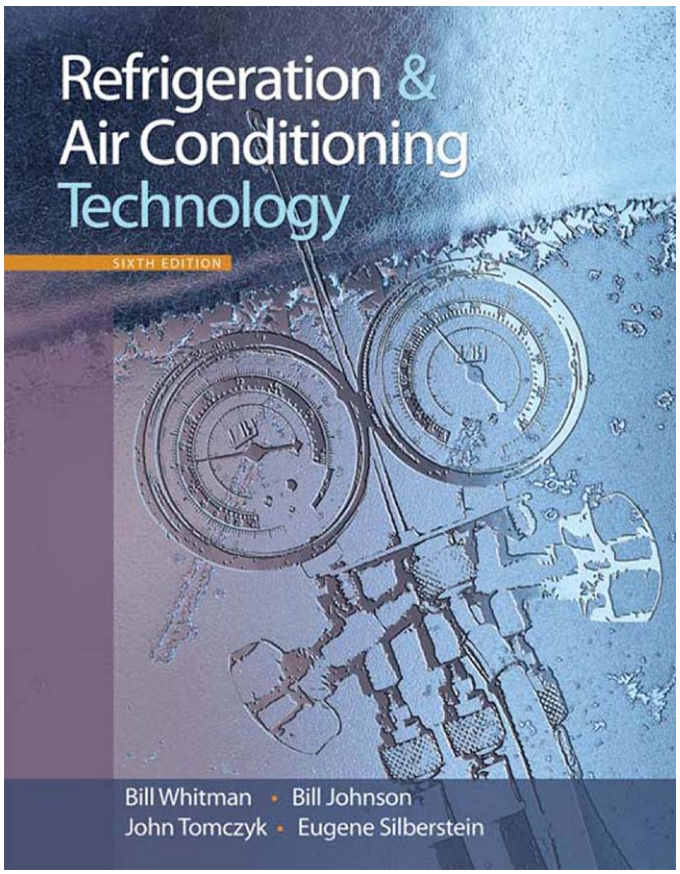
Refrigeration &
Air Conditioning
Technology
SIXTH EDITION
Bill Whitman • Bill Johnson
John Tomczyk • Eugene Silberstein

REFRIGERATION & AIR CONDITIONING TECHNOLOGY

6th Edition

William C. Whitman
William M. Johnson
John A. Tomczyk
Eugene Silberstein

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BRIEF TABLE OF CONTENTS

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Contents

CD in Back of Book Contains:

Preface

Refrigeration and Air Conditioning Technology is designed and written for students in vocational-technical schools and colleges, community colleges, and apprenticeship programs. The content is in a format appropriate for students who are attending classes full-time while preparing for their first job, for students attending classes part-time while preparing for a career change, or for those working in the field who want to increase their knowledge and skills. Emphasis throughout the text is placed on the practical applications of the knowledge and skills technicians need to be productive in the refrigeration and air-conditioning industry. The contents of this book can be used as a study guide to prepare for the Environmental Protection Agency (EPA) mandatory technician certification examinations. It can be used in the HVACR field or closely related fields by students, technicians, installers, contractor employees, service personnel, and owners of businesses.

This text is also an excellent study guide for the Industry Competency Exam (ICE), the North American Technician Excellence (NATE), the HVAC Excellence, the Refrigeration Service Engineers Society (RSES), the United Association (UA) STAR certification, and the Heating, Air Conditioning, and Refrigeration Distributors International (HARDI) voluntary HVACR technician certification and home study examinations.

The book is also written to correspond to the National Skill Standards for HVACR technicians. Previous editions of this text are often carried to the job site by technicians and used as a reference for service procedures. "Do-it-yourselfers" will find this text valuable for understanding and maintaining heating and cooling systems.

As general technology has evolved, so has the refrigeration and air-conditioning industry. A greater emphasis is placed on digital electronic controls and system efficiency. Every central split cooling system manufactured in the United States today must have a Seasonal Energy Efficiency Ratio (SEER) rating of at least 13. This energy requirement was mandated by federal law as of January 23, 2006. SEER is calculated on the basis of the total amount of cooling (in Btu) the system will provide over the entire season, divided by the total number watt-hours it will consume. Higher SEER ratings reflect a more efficient cooling system. Air-conditioning and refrigeration technicians are responsible for following procedures to protect our environment, particularly with regard to the handling of refrigerants. Technician certification has become increasingly important in the industry.

Global warming has become a major environmental issue. When HVACR systems are working correctly and efficiently, they will greatly reduce energy consumption and greenhouse gases. Organizations like the Green Mechanical Council (GreenMech) are advocates for the HVACR industry and assist the industry in meeting with government, educational, industry, and labor interests to find solutions to the world's global-warming problem. GreenMech has created a scoring system designed to help engineers, contractors, and consumers know the "green value" of each mechanical installation. The "green value" encompasses the system's energy efficiency, pollution output, and sustainability. Realtors, building inspectors, builders, and planning and zoning officials will now have some knowledge about and guidance on how buildings and mechanical systems are performing. Green buildings and green mechanical systems are becoming increasingly popular in today's world as a way to curb global warming.

TEXT DEVELOPMENT

This text was developed to provide the technical information necessary for a technician to be able to perform satisfactorily on the job. It is written at a level that most students can easily understand. Practical application of the technology is emphasized. Terms commonly used by technicians and mechanics have been used throughout to make the text easy to read and to present the material in a practical

way. Many of these key terms are also defined in the glossary. This text is updated regularly in response to market needs and emerging trends. Refrigeration and air-conditioning instructors have reviewed each unit. A technical review takes place before a revision is started and also during the revision process.

Illustrations and photos are used extensively throughout the text. Full-color treatment of most photos and illustrations helps amplify the concepts presented.

No prerequisites are required for using this text. It is designed to be used by beginning students, as well as by those with training and experience.

ORGANIZATION

Considerable thought and study has been devoted to the organization of this text. Difficult decisions had to be made to provide text in a format that would meet the needs of varied institutions. Instructors from different areas of the country and from various institutions were asked for their ideas regarding the organization of the instructional content.

The text is organized so that after completing the first four sections, students may concentrate on courses in refrigeration or air conditioning (heating and/or cooling). If the objective is to complete a whole program, the instruction may proceed until the sequence scheduled by the school's curriculum is completed.

New in This Edition

INTRODUCTORY MATERIALS

- A new section on the "green awareness" movement and global warming. Coverage includes key organizations and their present and future goals for how to accomplish green buildings and green mechanical rooms throughout the United States.
- A update on technician certification and on the key organizations that support either voluntary or mandatory technician certification.
- The new federal mandate of January 23, 2006 (requiring that every central split cooling system manufactured in the United States today have a Seasonal Energy Efficiency Ratio [SEER] rating of 13) is mentioned in the introductory material and is covered in more detail in appropriate chapters.
- The "Career Opportunities" section has been expanded to include a comprehensive list of career opportunities available in the HVACR field.

UNIT UPDATES

Most units have been updated to include advances or changes in technology, procedures, and/or equipment. The authors have added over 250 new images to this edition to emphasize the practical-application approach to the book. The following units have received major content additions and revisions for the sixth edition.

UNIT 1 Heat and Pressure

- More discussion of heat and pressure

UNIT 3 Refrigeration and Refrigerants

- Expanded coverage on pressure/enthalpy diagrams and system applications
- Detailed descriptions of "heat of work" and "heat of compression"

UNIT 4 General Safety Practices

New coverage on and photos illustrating the following topics:

- Cylinder safety
- Modern eye protection
- Pressure regulators
- Pressure relief valves
- Cylinder storage
- Electrical disconnects
- Emergency stop buttons
- Building signage
- First aid kits and placement
- Fire extinguishers and categories
- Refrigerant-specific leak detectors
- Evacuation plans
- Building directories
- Eye wash stations
- Emergency call stations

UNIT 5 Tools and Equipment

- Many new photos
- Discussion about how to choose and buy tools and instruments

UNIT 6 Fasteners

- New discussion about safety and fasteners

UNIT 7 Tubing and Piping

- Expanded coverage on tubing bending
- New coverage on new-generation mechanical piping connection systems

UNIT 8 System Evacuation

- Updated photos illustrating tools and instrumentation

UNIT 10 System Charging

- Expanded coverage on service valves
- Expanded discussion about the use of graduated charging cylinders

UNIT 14 Automatic Control Components and Applications

Updated photos illustrating the following:

- Transformers
- Heat anticipators
- Bimetal motor thermostats
- Oil safety controls

UNIT 15 Troubleshooting Basic Controls

- Expanded step-by-step electrical circuit evaluation

UNIT 16 Advanced Automatic Controls—Direct Digital Controls (DDC) and Pneumatics

New technical coverage on Direct Digital Control (DDC) systems. Many photos are included. The following systems and components are discussed:

- Controlled output devices
- Controlled environments
- Signal converters
- Control points
- Memory
- Control system components
- Active sensors
- Passive sensors
- Digital and analog inputs and outputs
- Set points
- Open control loops
- Closed control loops

- Feedback loops
- Control systems
- Control agents
- Controlled mediums
- DDC control system responsibilities

UNIT 17 Types of Electric Motors

- Additional information about motor slip and slip calculations

UNIT 18 Application of Motors

- Additional information about motor and blower speeds with respect to pulley sizes

UNIT 20 Troubleshooting Electric Motors

- Expanded coverage on the use of the belt tension gage
- Expanded coverage on motor evaluation methods. Instructs the technician on how to evaluate motors by measuring winding resistance

UNIT 21 Evaporators and the Refrigeration System

- Coverage on the 13 SEER federal mandate
- New photo illustrating the foaming of a compressor's sight glass
- Extensive coverage on the aluminum parallel-flow, flat-plate-and-fin evaporator (including many photos)

UNIT 22 Condensers

- New coverage on water-regulating valves (including photos)
- New, extensive coverage on the aluminum parallel-flow, flat-plate-and-fin condenser (including many photos)
- New coverage on cooling towers (including photos)
- New photos illustrating variable-frequency drives (VFDs)
- New, extensive coverage on low-ambient head pressure control valves (including many photos)

UNIT 23 Compressors

- New photos of and extensive coverage on discus compressors
- New photos of and extensive coverage on scroll compressors
- New photos of and coverage on the two-step modulating scroll compressor
- New coverage on digital capacity control for scroll compressors (including photos)
- New coverage on scroll compressor protection (including photos)
- New coverage on the high-efficiency, oil-free centrifugal compressor (including photos)

UNIT 25 Special Refrigeration System Components

- New diagrams and coverage on an automatic pumpdown system that will not short cycle the compressor while being pumped down

UNIT 30 Electric Heat

- New Service Calls

UNIT 32 Oil Heat

This expanded unit includes the following additions:

- New content on oil storage tanks
- New content on oil deaerators
- Expanded information about primary controls
- Expanded information about testing and evaluating oil-fired systems
- New content on oil-line vacuums and their effects on system and equipment operation
- New information about how to calculate the desired oil-line vacuum
- New information about how to compare one-pipe and two-pipe oil delivery systems

UNIT 33 Hydronic Heat

This expanded unit includes the following additions:

- Discussion of geothermal heat pumps as a heat source for hydronic heating systems
- More in-depth information about radiant heating systems (including installation types and applications)
- New content on primary–secondary pumping
- Expanded calculations relating the water flow, temperature differential, and Btu output of terminal units
- New information about multitemperature heating systems
- New information about outdoor reset

UNIT 34 Indoor Air Quality

- New discussion about filter applications
- Two new mold charts

UNIT 35 Comfort and Psychrometrics

- Expanded psychrometric chart

UNIT 36 Refrigeration Applied to Air Conditioning

- Discussion about attic ventilation
- Discussion about choosing equipment for different humidity locations
- Discussion about selecting equipment for different outside weather design conditions and maintaining equipment efficiencies

UNIT 37 Air Distribution and Balance

Additional coverage on system zoning that includes the following topics:

- Zoning using a single-speed blower
- Zoning using a variable-speed blower
- Adding zones to an existing system
- Airflow mathematical calculations

UNIT 39 Controls

- New photos of a solid-state anti-short-cycle timer, rooftop-unit air conditioner with parallel scroll compressors

UNIT 41 Troubleshooting

- Discussion about approach temperatures and temperature splits
- Information added to some of the illustrations
- Many new illustrations

UNIT 43 Air Source Heat Pumps

- Discussion of the Coefficient of Performance (COP) of heat pump systems
- Expanded discussion of heat pump defrost modes
- Expanded content on electrical strip heater operation in the emergency-heat, second-stage-heat, and defrost modes.

UNIT 45 Domestic Refrigerators

- Many new photographs

UNIT 46 Domestic Freezers

- Some new photographs

UNIT 47 Room Air Conditioners

- Some revised art
- Two new photographs

UNIT 48 High-Pressure, Low-Pressure, and Absorption Chilled-Water Systems

- Discussion about changing load conditions and equipment unloading
- Discussion about cooling for manufacturing processes
- More on variable-frequency drives (VFDs)
- Saving energy using building core heat to heat the perimeter of the building
- The use of subcooling in large systems
- Electronic expansion valves for large systems
- The use of electronic starters
- Power failure, low-voltage, voltage unbalance, and phase-reversal protection
- Several new photos

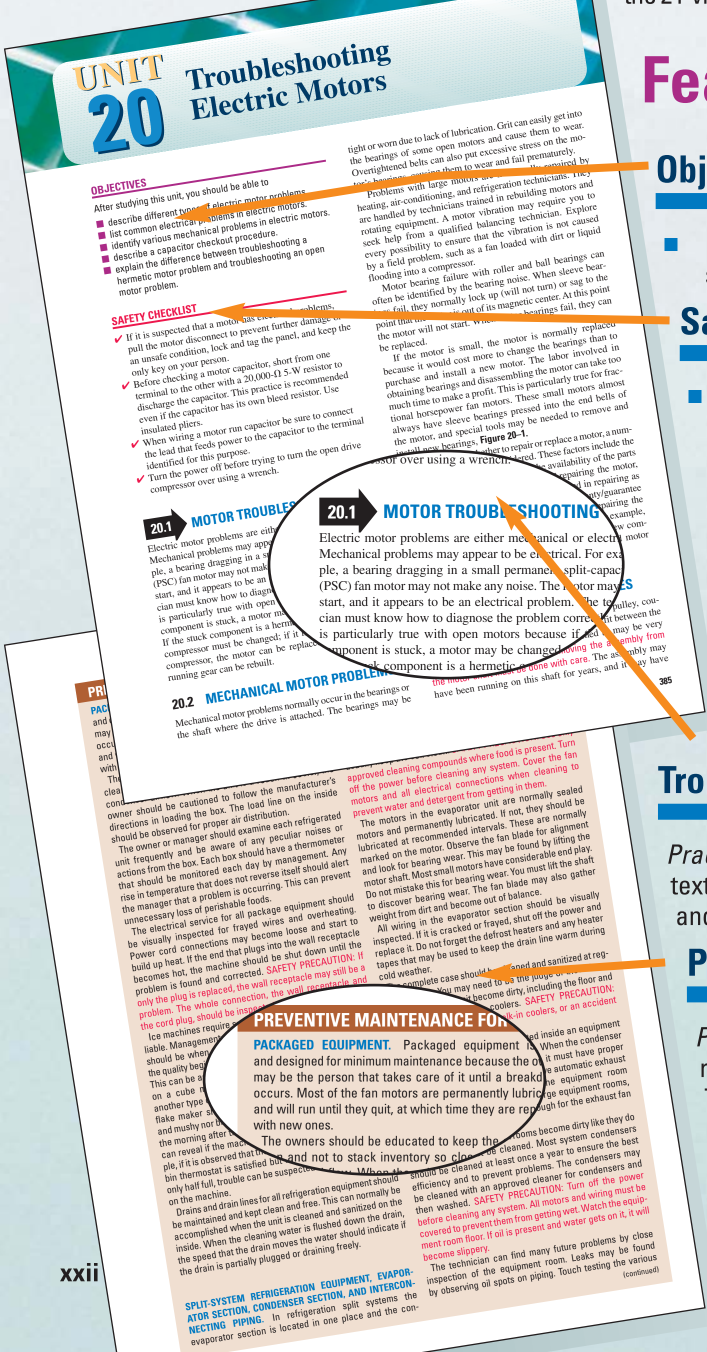
UNIT 50 Operation, Maintenance, and Troubleshooting of Chilled-Water Air-Conditioning Systems

- New discussion about and photos of many types of refrigerant, water, and steam valves
- Valve service information
- The servicing of pumps and strainers in water and steam systems
- Refrigerant safety in equipment rooms
- New photos and illustrations

How to Use the Text and Supplementary Materials

This text may be used as a classroom text, as a learning resource for an individual student, as a reference text for technicians on the job, or as a homeowner's guide. An instructor may want to present the unit objectives, briefly discuss the topics included, and assign the unit to be read. The instructor then may want to discuss the material with the students. This can be followed by the students completing the review questions, which can later be reviewed in class. The lecture outline provided in the *Instructor's Guide* may be utilized in this process. Lab assignments may be made at this time, followed by the students completing the lab review questions.

The instructor *e.resource CD* may be used to access a computerized test bank for end-of-unit review questions, teaching tips, PowerPoint® presentations, and more. The CD bound into the back of this book contains Section 9 (units 45–46) titled "*Domestic Appliances,*" as well as a unit titled "*Alternative Heating (Stoves, Fireplace Inserts, Solar),*" appendices, and two video-clip samples from the 24-video DVD series that accompanies this text.



Features of the Text

Objectives

- *Objectives* are listed at the beginning of each unit. The objective statements are kept clear and simple to give students direction.

Safety Checklists

- A *Safety Checklist* is presented at the beginning of each unit, when applicable, immediately following the Objectives. This checklist emphasizes the importance of safety and is included in units where "hands-on" activities are discussed.
- *Safety* is emphasized throughout the text. In addition to the safety checklist at the beginning of most units, safety precautions and techniques are highlighted in red throughout the text. It would be impossible to include a safety precaution for every conceivable circumstance that may arise, but an attempt has been made to be as thorough as possible. The overall message is to work safely whether in a school shop, laboratory, or on the job and to use common sense.

Troubleshooting

Practical troubleshooting procedures are an important feature of this text. Practical component and system troubleshooting suggestions and techniques are provided.

Preventive Maintenance

Preventive Maintenance Procedures are contained in many units and relate specifically to the equipment presented in that particular unit. Technicians can provide some routine preventive maintenance service when on other types of service calls as well as when on strictly maintenance calls. The preventive maintenance procedures provide valuable information for the new or aspiring technician and homeowner, as well as for those technicians with experience.

HVAC Golden Rules

Golden Rules for the refrigeration and air-conditioning technician give advice and practical hints for developing good customer relations. These "golden rules" appear in appropriate units.

Service Technician Calls

In many units, practical examples of service technician calls are presented in a down-to-earth situational format. These are realistic service situations in which technicians may find themselves. In many instances the solution is provided in the text, and in others the reader must decide what the best solution should be. These solutions are provided in the *Instructor's Guide.*

Recovery/Recycling/Reclaiming Retrofitting

Discussions relating to *recovery, recycling, reclaiming, retrofitting,* or other *environmental issues* are highlighted in orange throughout the text. In addition, one complete unit on refrigerant management is included—Unit 9, "Refrigerant and Oil Chemistry and Management—Recovery, Recycling, Reclaiming, and Retrofitting."

Green Awareness

As previously mentioned, global warming stemming from the uncontrolled rate of greenhouse gas emissions is a major global environmental issue. Buildings are the major source of demand for energy and materials. Because of this, buildings are the major source of greenhouse gases that are the by-products of the energy and materials. At the time of this writing, there are approximately 5 million commercial buildings and 125 million housing units in the United States. Surprisingly, almost every one of their mechanical systems is obsolete. Discussions relating to the green awareness movement (for example, lowering energy costs, reducing operating and maintenance costs, increasing productivity, and decreasing the amount of generated pollution) will be highlighted in green throughout the text.

Summary

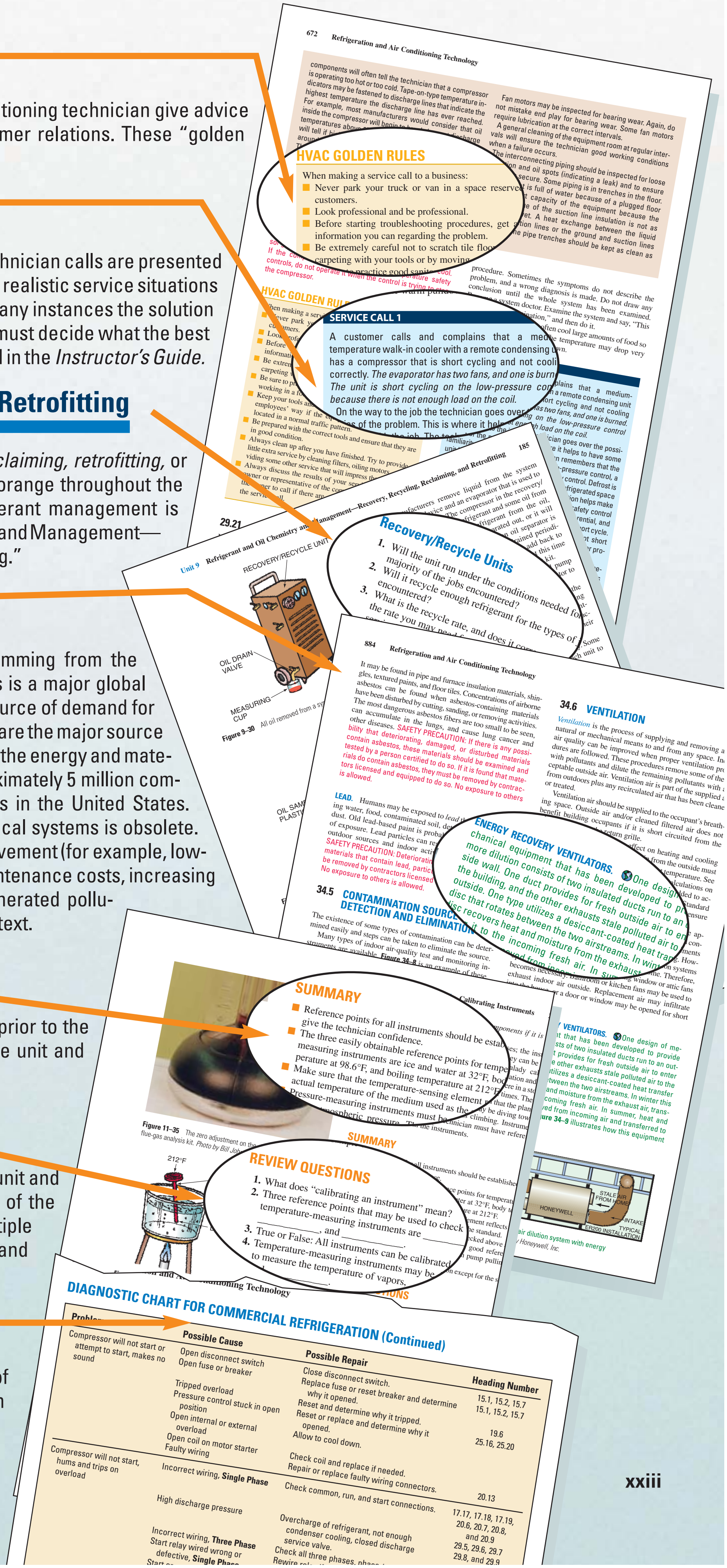
The *Summary* appears at the end of each unit prior to the Review Questions. It can be used to review the unit and to stimulate class discussion.

Review Questions

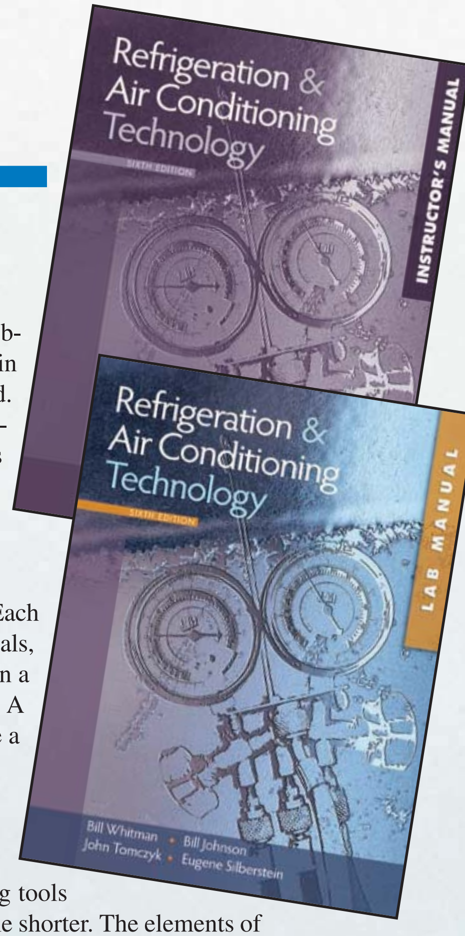
Review Questions follow the summary in each unit and can help to measure the student's knowledge of the unit. There are a variety of question types—multiple choice, true/false, short answer, short essay, and fill-in-the-blank.

Diagnostic Charts

Diagnostic Charts are included at the end of many units. These charts include material on troubleshooting and diagnosis.



Support Materials



Instructor's Guide

This guide includes an overview of each text unit, including a summary description, a list of objectives, and important safety notes. Diagnoses for service technician calls that are not solved in the text are provided. References to lab exercises associated with each unit's study are included. "Special Notes to Instructors" specify how to create an equipment "problem" for students to resolve during certain lab exercises. Answers to the review questions in the text and to all questions in the *Study Guide/Lab Manual* (review and lab exercises) are provided. ISBN: 1-4283-1938-7.

Study Guide/Lab Manual

The *Study Guide/Lab Manual* includes a unit overview, key terms, and a unit review test. Each lab includes a general introduction to the lab, including objectives, text references, tools, materials, and safety precautions. A series of practical exercises is provided for the student to complete in a "hands-on" lab environment. Maintenance instructions are given for the workstation and tools. A reference to the "Special Note to Instructors" in the *Instructor's Guide* describes how to create a system "problem" to be solved in the lab. ISBN: 1-4283-1937-9.

e.resource CD

This educational resource creates a truly electronic classroom. It is a CD-ROM containing tools and instructional resources that enrich the classroom and make the instructor's preparation time shorter. The elements of the *e.resource* link directly to the text to provide a unified instructional system. With the *e.resource* you can spend your time teaching, not preparing to teach. ISBN: 1-4283-1939-5.

Features contained in the *e.resource* include the following:

- **Syllabus.** This is the standard course syllabus for this textbook, providing a summary outline for teaching HVACR.
- **Teaching Tips.** Teaching hints provide the basis for a lecture outline to present concepts and material. Key points and concepts can be graphically highlighted for student retention.
- **Lecture Outlines.** Each unit has key topics outlined, and the key concepts that should be covered for each topic.
- **PowerPoint Presentation.** These slides provide the basis for a lecture outline to present concepts and material. Key points and concepts can be graphically highlighted for student retention.
- **Optical Image Library.** This database of key images (all in full color) taken from the text can be used in lecture presentations, transparencies, tests and quizzes, and PowerPoint presentations.
- **Computerized Test Bank.** Over 1,000 questions of varying levels of difficulty are provided in true/false, multiple choice, fill-in-the-blank, and short answer formats so you can assess student comprehension. This versatile tool enables the instructor to manipulate the data to create original tests.

Video DVD Set

A six-DVD video set addressing over 120 topics covered in the text is available. Each DVD will contain four 20-minute videos. To order the six-DVD set, reference ISBN: 1-4180-7283-4.

Audiobook

This is a collection of audio files covering every chapter in *Refrigeration and Air Conditioning Technology, Sixth Edition.* The audio files are organized into "A" head groupings (comparable to songs), which allow content to be accessed within the chapter. Once downloaded, MP3 audio files can be accessed on portable MP3 players or on PCs with standard media programs.

Students can listen to the chapter content being read while they follow along and look at the illustrations. References to page numbers are included at the beginning of each chapter. Chapter objectives, boxed features, figure and photo captions, and end-of-chapter elements are included as well (but not end-of-chapter questions). The audio files will not replace the book, since the artwork and photos are essential and must be viewed. ISBN: 1-4283-1942-5.

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Bill Whitman graduated from Keene State College in Keene, New Hampshire, with a bachelor's degree in Industrial Education. He received his master's degree in School Administration from St. Michael's College in Winooski, Vermont.

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Bill Johnson graduated from Southern Polytechnic with an associate's degree in Gas Fuel Technology and Refrigeration. He worked for the State of North Carolina's Weights and Measures Department; Coosa Valley Vocational and Technical Institute in Rome, Georgia; and the Trane Company of North Carolina. He also owned and operated an air-conditioning, heating, and refrigeration business for 10 years. He has unlimited licenses for North Carolina in heating, air conditioning, and refrigeration. Mr. Johnson taught heating, air-conditioning, and refrigeration installation, service, and design for 15 years at Central Piedmont Community College in Charlotte, North Carolina, and was instrumental in standardizing the heating, air-conditioning, and refrigeration curriculum for the state community college system. He is a member of Refrigeration Service Engineers Society (RSES). He has a series of articles on the Web site for the *Air Conditioning, Heating, Refrigeration News.* These articles are service situation calls for technicians.

John Tomczyk

John Tomczyk received his associate's degree in Refrigeration, Heating and Air-Conditioning Technology from Ferris State University in Big Rapids, Michigan; his bachelor's degree in Mechanical Engineering from Michigan State University in East Lansing, Michigan; and his master's degree in Education from Ferris State University. Mr. Tomczyk has worked in refrigeration, heating, and air-conditioning service; project engineering; and technical writing consultation for both the academic and industrial fields. His technical articles have been featured in the *Refrigeration News, Service and Contracting Journal,* and *Engineered Systems Journal.* He writes monthly for the *Air Conditioning, Heating, Refrigeration News* and is coauthor of an EPA-approved *Technician Certification Program Manual.* Mr. Tomczyk also is the author of the book *Troubleshooting and Servicing Modern Air Conditioning and Refrigeration Systems.* He is currently a professor in the Refrigeration, Heating, and Air-Conditioning Technology program at Ferris State University with 23 years of teaching experience. Mr. Tomczyk is a member of Refrigeration Service Engineers Society (RSES).

Eugene Silberstein

Eugene Silberstein has been involved in all aspects of the HVACR industry over the past 26 years—from field technician and system designer to company owner, teacher, administrator, consultant, and author. Mr. Silberstein is the author of *Heat Pumps* and *Residential Construction Academy: HVAC.* Mr. Silberstein is presently the Director and Professor of the HVAC/R Associates of Applied Sciences program on the Michael J. Grant Campus of Suffolk County Community College in Brentwood, New York. Mr. Silberstein is a member of the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) and the Refrigeration Service Engineers Society (RSES).

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Introduction

Refrigeration, as used in this text, relates to the cooling of air or liquids, thus providing lower temperatures to preserve food, cool beverages, make ice, and for many other applications. Air conditioning includes space cooling, heating, humidification, dehumidification, air filtration, and ventilation to condition the air and improve indoor air quality.

History of Refrigeration and Air Conditioning (Cooling)

Most evidence indicates that the Chinese were the first to store natural ice and snow to cool wine and other delicacies. Evidence has been found that ice cellars were used as early as 1000 B.C. in China. Early Greeks and Romans also used underground pits to store ice, which they covered with straw, weeds, and other materials to provide insulation and preserve it over a long period.

Ancient people of Egypt and India cooled liquids in porous earthen jars. These jars were set in the dry night air, and the liquids seeping through the porous walls evaporated to provide the cooling. Some evidence indicates that ice was produced due to the vaporization of water through the walls of these jars, radiating heat into the night air.

In the eighteenth and nineteenth centuries, natural ice was cut from lakes and ponds in the winter in northern climates and stored underground for use in the warmer months. Some of this ice was packed in sawdust and transported to southern states to be used for preserving food. In the early twentieth century, it was still common in the northern states for ice to be cut from ponds and then stored in open ice houses. This ice was insulated with sawdust and delivered to homes and businesses.

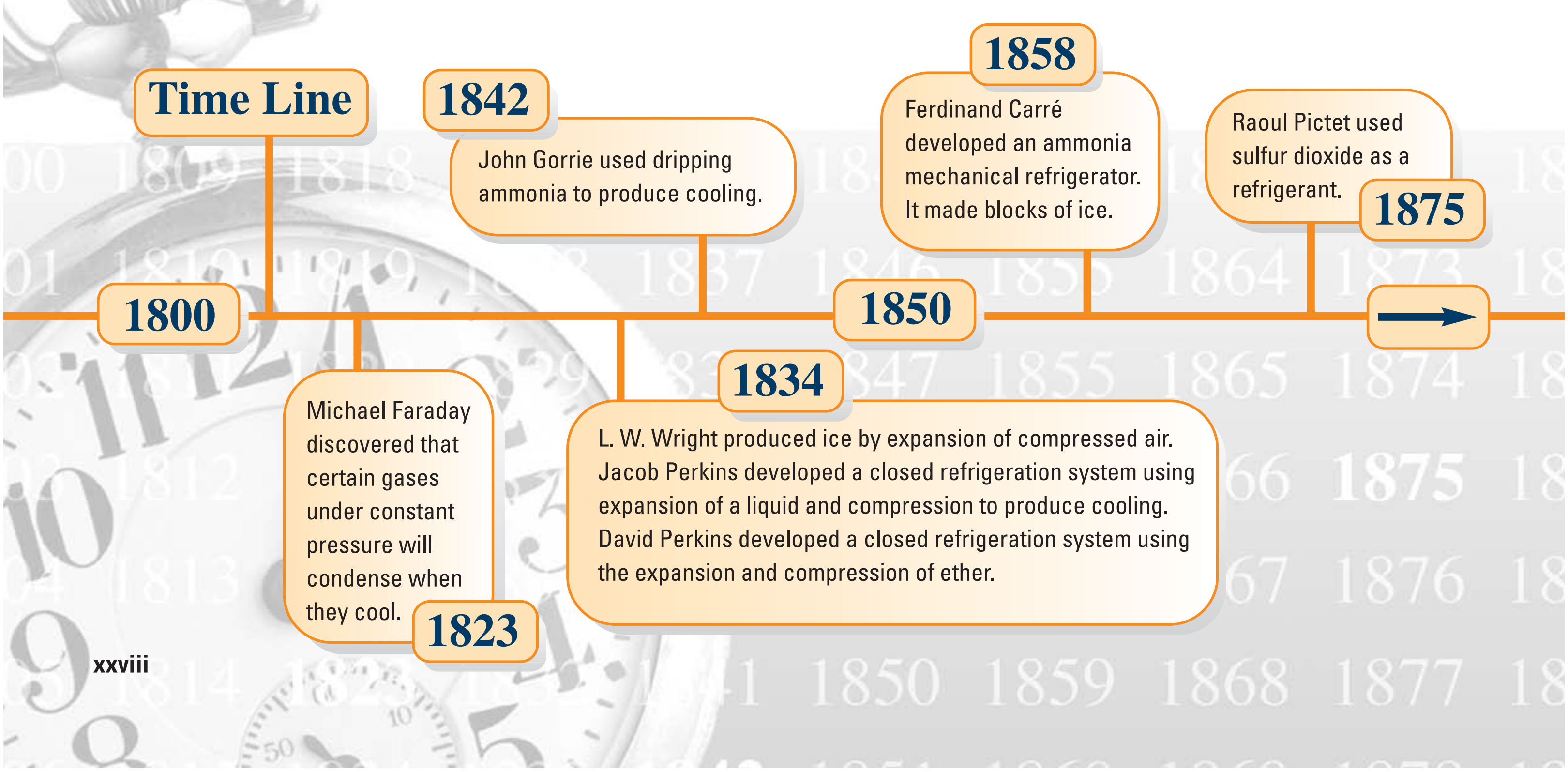
In 1823, Michael Faraday discovered that certain gases under constant pressure will condense when they cool. In 1834, Jacob Perkins, an American, developed a closed refrigeration system using liquid expansion and then compression to produce cooling. He used ether as a refrigerant, a hand-operated compressor, a water-cooled condenser, and an evaporator in a liquid cooler. He was awarded a British patent for this system. In Great Britain during the same year, L. W. Wright produced ice by the expansion of compressed air.

In 1842, Florida physician John Gorrie placed a vessel of ammonia atop a stepladder, letting the ammonia drip, which vaporized and produced cooling. This basic principle is used in air conditioning and refrigeration today.

In 1856, Australian inventor James Harrison, an emigrant from Scotland, used an ether compressor. He used ammonia on an experimental basis but used ether in equipment that was previously constructed.

In 1858, a French inventor, Ferdinand Carré, developed a mechanical refrigerator using liquid ammonia in a compression machine. He made blocks of ice. Generally, mechanical refrigeration was first designed to produce ice.

In 1875, Raoul Pictet of Switzerland used sulfur dioxide as a refrigerant. Sulfur dioxide is also a lubricant and could be used as the refrigerant and as a lubricant for the compressor. This refrigerant was used frequently after 1890 and was used on British ships into the 1940s.



In 1881, Gustavus Swift worked to develop refrigeration railcars that were used at that time, and in 1890, Michael Cudahy improved refrigeration railcars.

In 1894, the Audiffren-Singrün refrigeration machine was patented by a French priest and physicist, Father Marcel Audiffren. Its original design was for cooling liquids, such as wine, for the monks. Its compressor design is of the Scotch-yoke type. Most units used sulfur dioxide as the refrigerant.

In 1902, Willis Carrier, the "father of air conditioning," designed a humidity control to accompany a new air-cooling system. He pioneered modern air conditioning. In 1915, he, along with other engineers, founded Carrier Engineering, now known as Carrier Corporation.

In 1918, the name of Electro Automatic Refrigeration Corporation was changed to Kelvinator. This is also when the first of the Kelvinator household units were sold. The refrigerator was a remote-split type in which the condensing unit was installed in the basement and connected to an evaporator in a converted icebox in the kitchen.

Guardian Refrigerator Company developed a refrigerator they called the "Guardian." General Motors purchased Guardian in 1919 and developed the refrigerator they named Frigidaire. In 1929, refrigerator sales topped 800,000. The average price fell from $600 in 1920 to $169 in 1939.

In 1923, Nizer introduced a water-cooled compressor and condensing unit for ice cream cabinets. This unit was considered the first ice cream unit for the market. Nizer soon merged into the Kelvinator Company.

In 1923–1926, Savage Arms were among the first automatically controlled commercial units to appear. The Savage Arms compressor had no seals, no pistons, and no internal moving parts. A mercury column compressed the refrigerant gas as the entire unit rotated. The compressor was practically noiseless.

In 1928, Paul Crosley introduced an absorption-type refrigeration machine so that people could have refrigeration in rural areas where there was no electricity. Ammonia and water, charged by generating the system over a kerosene burner, could lower the inside temperature to 43°F or less. Ice cubes actually could be made for a period of about 36 hours, depending on the room temperature.

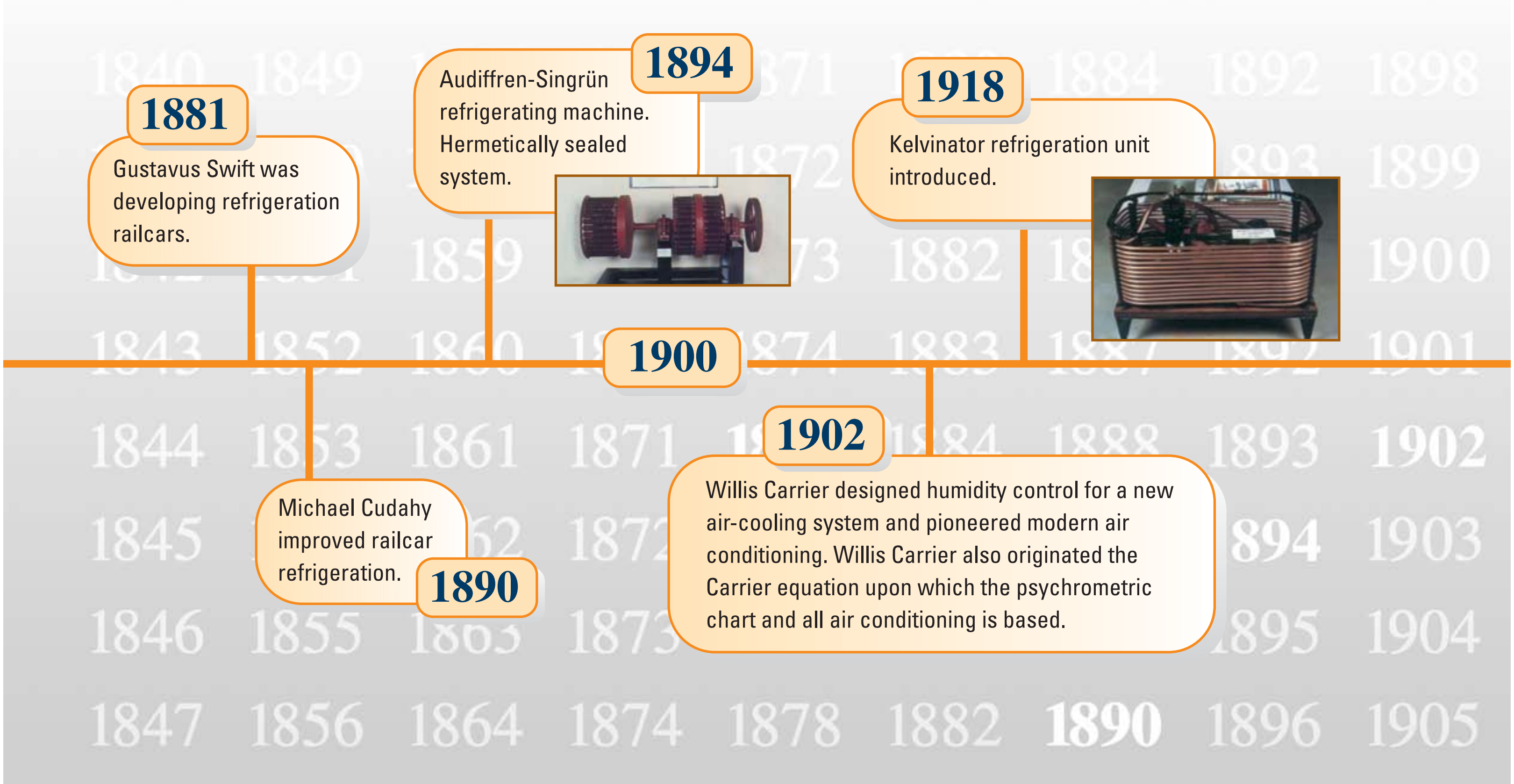
Many different refrigerants have been developed over the years. The refrigerant R-12, a chlorofluorocarbon (CFC), was developed in 1931 by Thomas Midgley of Ethyl Corporation and C. F. Kettering of General Motors. It was produced by DuPont. By the 1930s refrigeration was well on its way to being used extensively in American homes and commercial establishments.

In 1939, the Copeland Company introduced the first successful semi-hermetic (Copelametic) field-serviceable compressor. Three engineering changes made these compressors successful:

1. Cloth-insulated motor windings were replaced with Glyptal insulation.
2. Neoprene insulation replaced porcelain enamel in the electric terminals.
3. Valves were redesigned to improve efficiency.

In 1974, two professors from the University of California, Sherwood Rowland and Mario Molina, presented the "ozone theory." This hypothesis stated that released CFC refrigerants were depleting the earth's protective ozone layer. Scientists conducted high-altitude studies and concluded that CFCs were linked to ozone depletion.

Representatives from the United States, Canada, and more than 30 other countries met in Montreal, Canada, in September, 1987, to try to solve the problems of released refrigerants and the effect they had on ozone depletion. This meeting was known as the Montreal Protocol. This Protocol was ratified by 100 nations in 1989 and mandated a global production freeze on CFCs that froze their production levels back to 1986 levels. The Protocol also froze production of HCFCs to 1986 levels, which was to start in 1992. In addition, the Protocol placed a tax-rate



schedule on CFC refrigerants. As research on ozone depletion continues today, reassessments and updates to the Montreal Protocol also continue. At the time of writing this edition, the most current updates are as follows:

- 1990 (November)—President George H. W. Bush signed the Clean Air Act amendments which initiated production freezes and bans on certain refrigerants.
- 1992 (July)—The EPA made it against the law to intentionally vent CFC and HCFC refrigerants into the atmosphere.
- 1993—The EPA mandated the recycling of CFC and HCFC refrigerants.
- 1994 (November)—The EPA mandated a technician certification program deadline. Working HVACR technicians had to be EPA-certified by this date.
- 1995 (November)—The EPA made it against the law to intentionally vent alternative refrigerants (HFCs and all refrigerant blends) into the atmosphere.
- 1996—The EPA made it against the law to manufacture CFC refrigerants.
- 1996—The EPA put into place a gradual HCFC production phaseout schedule, which will totally phase out the production of HCFC refrigerants by the year 2030.
- 1998 (June)—The EPA proposed new regulations on recovery/recycling standards, equipment leak rates, and alternative refrigerants.

In 1997, the Kyoto Protocol was introduced, with the objective of reducing worldwide global-warming gas emissions. The greenhouse effect, or global warming, had become a major environmental issue.

From 1997–2000, voluntary HVACR technician certification became a major focus.

From 1998–2008, the AC&R Safety Coalition; Air Conditioning and Refrigeration Institute (ARI); Heating, Air Conditioning, and Refrigeration Distributors International (HARDI); Carbon Monoxide Safety Association (COSA); Green Mechanical Council; HVAC Excellence; North American Technician Excellence (NATE); Refrigeration Service Engineers Society (RSES); and the United Association of Journeymen and Apprentices (UA) became important players in voluntary HVACR technician certification and home study examinations.

R-410A, an efficient and chlorine-free HFC-based refrigerant blend for residential and light-commercial air-conditioning applications is used with the scroll compressor for greater efficiencies.

Today, every central split cooling system manufactured in the United States must have a Seasonal Energy Efficiency Ratio (SEER) rating of at least 13. This energy requirement was mandated by federal law as of January 23, 2006.

In 2007, global warming became a major environmental issue. A scoring system was designed to help engineers, contractors, and consumers know the "green value" of each mechanical installation. The "green value" encompasses the system's energy efficiency, pollution output, and sustainability. Green buildings and green mechanical systems are becoming increasingly popular in today's world as a way to curb global warming.

Green Awareness

As mentioned previously, global warming stemming from the uncontrolled rate of greenhouse gas emissions is a major global environmental issue. Most of the sun's energy reaches the earth as visible light. After passing through the atmosphere, part of this energy is absorbed by the earth's surface and is converted into heat energy. The earth, warmed by the sun, radiates heat energy back into the atmosphere toward space. Naturally occurring gases and lower atmospheric pollutants such as CFCs, HCFCs, HFCs, carbon dioxide, carbon monoxide, water vapor, and many other chemicals absorb, reflect, and/or refract the earth's infrared radiation and prevent it from escaping the lower atmosphere. Carbon dioxide, occurring mainly from the burning of fossil fuels, is the major global-warming gas today. Humans are chiefly responsible for many of these greenhouse gases. This process slows the earth's heat loss, making the earth's surface warmer than it would be if this heat energy had passed unobstructed through the atmosphere into space. The warmer earth's surface then radiates more heat until a balance is established

1919
Guardian Refrigerator Company developed a refrigerator they called the Guardian. General Motors purchased Guardian in 1918 and the name was changed to Frigidaire.

1928
Crosley Icy Ball—An absorption-type refrigerator machine provided refrigeration in rural areas without electricity.

1910

1923
Nizer water-cooled compressor and condenser for ice cream cabinets. Nizer made the first ice cream unit for the market. Nizer soon merged into Kelvinator.

1926
Savage Arms ice cream unit introduced. It contained a unique mercury column compressor with no seals, pistons, or lubrication.

between incoming and outgoing energy. This warming process is called *global warming* or the *greenhouse effect.*

Over 70% of the earth's fresh water supply is either in ice cap or glacier form. Scientists are concerned that these ice caps or glaciers will melt if the average earth temperature rises too much, thereby causing increased water levels. Scientific consensus is that we must limit the rise in global temperatures to less than 2 degrees centigrade above pre-industrial levels to avoid disastrous impacts. At a rise of 2 degrees centigrade, millions of people will likely be displaced from their homes because of rising water levels. Food production will decline, rivers will become too warm to support fish, coral reefs will die, snow packs will decrease and threaten water supplies, weather will become unpredictable and extreme, and many plant and animal species will die and become extinct.

Nineteen of the hottest 20 years on record have occurred since 1980. Atmospheric carbon dioxide levels are now at their highest. Half of the world's oil is gone and other natural resources are dwindling. The average American uses 142 gallons of water per day, and in some regions of the country water is drying up. Because of this, slowing the growth rate of greenhouse gas emissions and then reversing it has become a global effort.

Buildings are the major source of demand for energy and materials. Because of this, buildings are the major source of greenhouse gases that are the by-products of the energy and materials. At the time of this writing, there are approximately 5 million commercial buildings and 125 million housing units in the United States. Surprisingly, almost every one of their mechanical systems is obsolete. It is these global-warming scares, the rising price of fuels, the scarcity of clean water, and the ever-growing waste stream that demands improvements in our homes and businesses today. Trained contractors, with the help of the government, installers, builders, manufacturers, and educators, must renovate and improve the efficiency of these buildings and mechanical systems.

In the United States, buildings account for

- 36% of total energy used.
- 65% of electrical consumption.
- 30% of greenhouse gas emissions.
- 30% of raw materials used.
- 30% of waste output (136 millions tons annually).
- 12% of potable water consumption.

Organizations like the Green Mechanical Council (GreenMech) and the United States Green Building Council (USGBC) are setting goals to use fewer fossil fuels in existing and new buildings. Some of these goals are listed below:

- All new buildings, developments, and major renovation projects must be designed to use one-half of the fossil fuel energy they would typically consume.
- The fossil fuel reduction standard for all new buildings must be increased to
  - 60% in 2010.
  - 70% in 2015.
  - 80% in 2020.
  - 90% in 2025.
- By 2030, new buildings must be carbon-neutral. Carbon-neutral means that they cannot use any fossil-fuel greenhouse-gas-emitting energy to operate.
- Joint efforts must be made to change existing building standards and codes to reflect these targets.

Builders can accomplish these goals by choosing proper siting, building forms, glass properties and locations, and material selection, and by incorporating natural heating, cooling, ventilating, and lighting strategies. Renewable energy sources such as solar, wind, biomass, and other carbon-free sources can operate equipment within the building.

The Leadership in Energy and Environmental Design (LEED) is a voluntary national rating system for developing high-performance, sustainable buildings. It is referred to as the LEED Green Building Rating System. It was established by the

1929
Household refrigerator sales topped 800,000.

1930

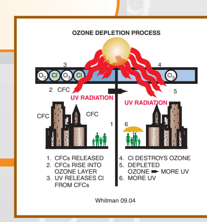
1931
Refrigerant R-12 was developed by Thomas Midgley and C. F. Kettering.

1939
First successful semi-hermetic (Copelametic) compressor introduced by the Copeland Company. Sales started in 1939. It was a field serviceable compressor.

1935–65
A number of chlorofluorocarbons (CFCs) were developed during this period.

1970

1974
Professors Rowland and Molina presented the "ozone theory" that CFCs were depleting the ozone layer.



USGBC in 1999 and is widely recognized as the third-party verification system and guideline for measuring what constitutes a green building.

A LEED-certified building means that it has achieved at least a minimum standard as judged in six categories:

1. Sustainable sites
2. Water efficiency
3. Energy and atmosphere (HVAC systems)
4. Materials and resources
5. Indoor environmental quality
6. Innovation and design process

Points are awarded in each individual category, depending on how the building meets the category's requirements. In order to be LEED certified, a building must receive a minimum of 26 points out of the 69 points available. The energy and atmosphere category deals with the HVAC systems and consists of one-third of the total LEED points. This category addresses the amount of energy the HVAC system consumes, the environmental impact of generating this energy, and the ozone depletion potential of the refrigerant used in the HVAC system.

There are four levels of LEED certification. They are as follows:

1. Certified (26–32 points)
2. Silver (33–38 points)
3. Gold (39–51 points)
4. Platinum (52–69 points)

The USGBC membership, which is composed of every sector of the building industry and consists of over 9000 organizations, developed and continue to refine LEED. LEED addresses all building types including new construction, commercial interiors, core and shell, operation and maintenance, homes, neighborhoods, campuses, schools, health care, laboratories, and lodging. LEED promotes expertise in green building by offering project certification, professional accreditation, and training. LEED emphasizes state-of-the-art strategies for sustainable site development, water savings, energy efficiency, material selection, and indoor environmental quality. According to the United Nations World Commission on Environment and Development, a sustainable design "meets the needs of the present without compromising the ability of future generations to meet their own needs." Companies looking to "go green," or incorporate sustainable design into their facilities, want products that help them lower energy costs, reduce operating and maintenance costs, increase productivity, and decrease the amount of pollution that is generated. Sustainable buildings typically have lower annual costs for energy, water, maintenance/repair, and other operating expenses.

The green awareness movement isn't just a temporary "buzz word" that will fade away with time. It is a movement that will be rapidly gaining momentum in the coming years. If contractors want to remain competitive, they must obtain the necessary training with regard to green building and LEED certification.

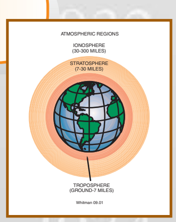
History of Home and Commercial Heating

Human beings' first exposure to fire was probably when lightning or another natural occurrence, such as a volcanic eruption, ignited forests or grasslands. After overcoming the fear of fire, early humans found that placing a controlled fire in a cave or other shelter could create a more comfortable living environment. Fire was often carried from one place to another. Smoke was always a problem, however, and methods needed to be developed for venting it outside. An example seen in later years was that of Native Americans venting smoke through holes at the peak of their tepees, and some of these vents were constructed with a vane that could be adjusted to prevent downdrafts.

Fireplaces were common in Europe and North America and were vented through chimneys. Early stoves were found to be more efficient than fireplaces. These early stoves were constructed of a type of firebrick, ceramic materials, or iron.

In the mid-eighteenth century, a jacket for the stove and a duct system were developed. The stove could then be located at the lowest place in a structure; the air in the jacket around the

1985 Stratospheric ozone hole discovered.



1989 Montreal protocol ratified by 100 countries.

1990 Clean Air Act amendments. Production freezes and bans on certain refrigerants. Signed by President George H. W. Bush, November, 1990.

1992 The EPA made it against the law to intentionally vent CFC and HCFC refrigerants into the atmosphere.

1994 Mandatory EPA technician certification required to service refrigeration and A/C equipment or to buy ozone-depleting refrigerants as of November, 1994.

stove was heated and would rise through the duct system and grates into the living area. This was the beginning of the development of circulating warm air heating systems.

Boilers that heated water were developed, and this water was circulated through pipes in duct systems. The water heated the air around the pipes. This heated air passed into the rooms to be heated. Radiators were then developed. The heated water circulated by convection through the pipes to the radiators, and heat was passed into the room by radiation. These early systems were forerunners of modern hydronic heating systems.

Career Opportunities

With the advancement of technology that is being spurred on by the need for increased energy efficiencies, the HVACR industry is rapidly changing. The career opportunities available in HVACR for those who have acquired formal technical training coupled with field experience is unlimited. Schools that provide excellent technical training in HVACR are becoming easier to identify through HVACR program accreditation. As new equipment becomes more technically challenging and the existing workforce continues to age, the available employment positions will continue to outnumber applicants for the foreseeable future. This shortfall in available competent HVACR service technicians is being addressed through the cooperative efforts of educational institutions, labor unions, employers, and manufacturers. Many organizations offer apprenticeship opportunities that can lead to high-income positions. Manufacturers are also teaming up with select educational institutions across North America to help develop the next generation of HVACR technician.

People in the United States expect to be comfortable. In cold weather, they expect to be able to go inside and be warm, and in the warmer climates, they expect to be able to go inside and be cool. They expect beverages to be cold when they want them to be and their food to be properly preserved.

Many buildings are constructed so that the quality of the air must be controlled by specialized equipment. The condition of the air must be controlled in many manufacturing processes. Heating and air-conditioning systems control the temperature, humidity, and total air quality in residential, commercial, industrial, and other types of buildings. Refrigeration systems are used to store and transport food, medicine, and other perishable items. Refrigeration and air-conditioning technicians design, sell, install, or maintain these systems. Many contractors and service companies specialize in commercial refrigeration. The installation and service technicians employed by these companies install and service refrigeration equipment in supermarkets, restaurants, hotels/motels, flower shops, and many other types of retail and wholesale commercial businesses.

Other contractors and service companies may specialize in air conditioning. Many specialize in residential-only or commercial-only installation and service; others may install and service both residential and commercial equipment up to a specific size. Air conditioning may include cooling, heating, humidifying, dehumidifying, or air cleaning. The heating equipment may include gas, oil, electric, or heat pumps. The number of each type of installation will vary from one part of the country to another, depending on the climate and availability of the heat source. The heating equipment may be a space-heating (air distribution) type or a hydronic furnace. The hydronic furnace heats water and pumps it to the space to be heated, where one of many types of heat exchangers transfers the heat to the air.

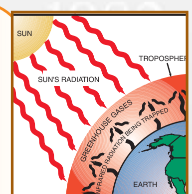
Technicians may specialize in installation or service of this equipment, or they may be involved with both. Other technicians may design installations or work in the sales area. Sales representatives may be in the field selling equipment to contractors,

1995
Unlawful to intentionally vent alternative refrigerants (HFCs and all refrigerant blends) into the atmosphere as of November, 1995.

1995

1996
Gradual HCFC production phaseout schedule with the total phaseout of HCFC refrigerants in the year 2030. Phaseout of CFC refrigerants.

1997
Kyoto Protocol introduced, intended to reduce worldwide global warming gases. Global warming has become a major environmental issue.



1997–2000
Voluntary HVACR technician certification became a major focus.

1998–2005
R-410A, an efficient and chlorine-free HFC-based refrigerant blend for residential and light-commercial air-conditioning applications, is used with the scroll compressor for greater efficiencies.

2006
"Minimum 13 SEER" required for 1 1/2- to 5-ton unitary equipment and split/ packaged air conditioners and heat pumps.

2007
"Green awareness"—Green mechanical systems and green buildings become increasingly popular as a way to curb global warming and conserve energy.

businesses, or homeowners; others may work in wholesale supply stores. Other technicians may represent manufacturers, selling equipment to wholesalers and large contractors.

Many opportunities exist for technicians to be employed in the industry or by companies owning large buildings. These technicians may be responsible for the operation of air-conditioning equipment, or they may be involved in the service of this equipment.

Opportunities also exist for employment in servicing household refrigeration and room air conditioners. This would include refrigerators, freezers, and window or through-the-wall air conditioners.

Opportunities are available for employment in a field often called transport refrigeration. This includes servicing refrigeration equipment on trucks or on large containers hauled by trucks and ships.

Most modern houses and other buildings are constructed to keep outside air from entering, except through planned ventilation. Consequently, the same air is circulated through the building many times. The quality of this air may eventually cause a health problem for people spending many hours in the building. This indoor air quality (IAQ) presents another opportunity for employment in the air-conditioning field. Technicians clean filters and ducts, take air measurements, check ventilation systems, and perform other tasks to help ensure healthy air quality.

Other technicians work for manufacturers of air-conditioning equipment. These technicians may be employed to assist in equipment design, in the manufacturing process, or as equipment salespersons.

Following is a list of many career opportunities in the HVACR field:

- Field service technician
- Service manager
- Field supervisor
- Field installer
- Journeyman
- Project manager
- Job foreman
- Application engineer
- Controls technician
- Draftsperson
- Contractor
- Lab technician
- Inspector
- Facilities technician
- Instructor
- Educational administrator
- Inside/outside sales
- Sales manager
- Research and development
- Estimator

Technician Certification Programs

History. Even though mandatory technician certification programs are in place today, the EPA originally did not consider them as its lead option. As a matter of fact, the EPA initially thought private incentives would ensure that technicians were properly trained in refrigerant recycling and recovery. The EPA also stated that it would play an important role through a voluntary technician certification program by recognizing those who provide and participate in voluntary technician training programs that meet certain minimum standards. The EPA also thought that a mandatory certification program would be an administrative burden for it. The EPA then requested public comments on a mandatory versus voluntary technician certification program. More than 18,000 comments were in favor of a mandatory program, and only 142 were in favor of a voluntary program. Most of the 18,000 in favor of the mandatory certification program were major trade organizations and technicians themselves. Manufacturers of recovery and recycling equipment, along with environmental organizations, also supported mandatory certifications. They believed it would increase compliance with venting, recovery, and recycling laws and the general safe handling of refrigerants. The following were reasons given by those favoring mandatory technician certification:

- Improve refrigerant leak detection techniques
- Promote awareness of problems relating to venting, recovery, and recycling of refrigerants
- Improve productivity and cost savings through proper maintenance practices
- Ensure environmentally safe service practices
- Gain more consumer trust
- Receive more liability protection
- Ensure that equipment is properly maintained
- Educate technicians on how to effectively contain and conserve refrigerants
- Create uniform and enforceable laws
- Foster more fair competition in the regulated community

With these comments in mind, the EPA decided that mandatory technician certification would increase fairness by ensuring that all technicians are complying with today's rules. The EPA also said that a mandatory certification program would also enhance the EPA's ability to enforce today's rules by providing a tool to use against intentional noncompliance: the ability to revoke the technician's certification. The EPA then created a mandatory technician certification program that mandated that all technicians be certified after November 14, 1994.

All technicians now must pass an examination administered by an approved EPA testing organization in the private sector in order to purchase refrigerant and to work on equipment that contains refrigerant. *Technicians* for mandatory certification are defined as installers, contractor employees, in-house service personnel, and anyone else who installs, maintains, or repairs equipment that might reasonably have the opportunity to release CFCs or HCFCs into the atmosphere. The EPA created three separate technician certification types:

- Small appliances
- High- and very high-pressure appliances
- Low-pressure appliances

Persons who successfully pass a *core of questions* on stratospheric ozone protection and legislation and also pass one of the three certification types will be certified in that type. If all three certification types are passed, a person will be *universally* certified. To this date, the EPA is not requiring recertification. However, it will be the technicians' responsibility to keep updated on new technologies and governmental rule changes. By creating certification types, the EPA allowed technicians to be tested on information concerning equipment and service practices that the technicians primarily service and maintain.

Although training programs are beneficial, participation in a training program is not required by today's rule. If training

programs are requested by technicians, they will be administered by the private sector to create price-competitive training programs. Many national educational and trade organizations such as the AC&R Safety Coalition; Air Conditioning and Refrigeration Institute (ARI); Air Conditioning Contractors of America (ACCA); Heating, Air Conditioning, and Refrigeration Distributors International (HARDI); Carbon Monoxide Safety Association (COSA); Educational Standards Corporation (ESCO); Environmental Protection Agency (EPA); Ferris State University (FSU); Green Mechanical Council (GreenMech); HVAC Excellence; North American Technician Excellence (NATE); Refrigeration Service Engineers Society (RSES); and the United Association of Journeymen and Apprentices (UA) have developed training and/or testing programs. These programs are specifically intended to help technicians comply with the July 1, 1992, refrigerant venting law. Unit 9 of this text, "Refrigerant and Oil Chemistry and Management—Recovery, Recycling, Reclaiming, and Retrofitting," will give more detailed information on the EPA's mandatory technician certification program, including details on the specific types of certification tests and specifications. For a complete list of EPA approved certifying organizations, contact the EPA hotline at 1-800-296-1996.

Certification Programs. Technician certification programs can be divided into two categories. They are:

- ***Mandatory technician certification programs***
- ***Voluntary technician certification programs***

Mandatory technician certification programs are covered in the preceding paragraphs and in Unit 9. Voluntary technician certification programs are becoming popular because they are industry led and are much more comprehensive in nature when compared to mandatory certification programs. They give technicians an educational opportunity from the beginning to the end of their careers. These programs allow technicians to become recognized at their level of expertise. They also allow technicians to excel to higher levels of competence. Their diverse nature allows for almost every avenue of the industry to be covered. Voluntary certification testing is based on the courses taken for each level, with an outline and roadmap on what material will be covered on the test and where to find the material.

Why Technicians Should Become Certified. As mentioned earlier, mandatory technician certification legally allows the technician to purchase ozone-depleting refrigerants and work on equipment that contains refrigerant. Some advantages of having both mandatory and voluntary technician certifications are that

- customers tend to ask for certified technicians because of their reliability and good workmanship.
- equipment manufacturers develop faith in certified technicians and have a sense of well-being when they know the job has been accomplished by a certified technician.
- higher standards are set on the job by certified technicians, giving them more respect, recognition, trust, higher pay, and a higher quality of life in the long run.
- employers would rather hire a certified technician, because they know certified technicians care more about their reputation, customer relations, and overall professionalism.
- certification gives the technician a status symbol for other technicians to work up to.
- certified technicians have proven technical proficiencies with measured capabilities.

National Skill Standards

The National Skill Standards (NSS), as interpreted by the Vocational-Technical Education Consortium of States (VTECS) for Heating, Air Conditioning, and Refrigeration Technicians, were funded by the U.S. Department of Education as part of 22 projects from the National Skill Standards Board from 1992 to 1998. The NSS were created by a joint effort of committees composed of heating, air-conditioning, and refrigeration industry professionals. These skill standards not only help technicians identify the skills and knowledge needed for their occupation but also assess their weaknesses and/or needs for additional training.

Skill standards are often described as workplace behaviors, technical skills, and the general body of knowledge required of technicians to be successful, productive, and competitive in today's workforce. As HVACR manufacturers increase the efficiency and sophistication of their equipment, technicians require additional updated information as well as a sound technical skills base to maintain, install, and service this equipment. An increased number of environmental regulations for more energy efficient and environmentally friendly HVACR equipment have also created a new knowledge and skills base for technicians to learn and use on their jobs.

Although it is difficult to provide all users of this text with information on the vast array of issues covered in the NSS, the authors have made every effort to do so. Hopefully, both private and public institutions as well as industry will use our comprehensive book to provide both students and workers with the competencies needed for successful employment and advancement in the ever-changing and growing technical HVACR field.

The NSS are divided into three main areas with subdivisions as follows:

- **Core Knowledge**
  - *Communications*
  - *Mathematics*
  - *Science*
- **Occupational-Specific Skills**
  - *Core skills*
  - *Occupational-specific skills*
- **Workplace Behaviors**
  - *Ethics*
  - *Environment*
  - *Communications*
  - *Professionalism*
  - *Problem solving*

The *core skills* consist of:

- Safety and environment
- Electrical principles
- Electric motors
- Controls
- Refrigeration principles and practices
- Heating principles and practices
- Air-conditioning principles and practices
- Piping principles and practices

The *occupational-specific skills* consist of:

- Residential and light-commercial heating
- Residential and light-commercial air conditioning
- Residential and light-commercial heat pumps
- Commercial conditioned-air systems
- Commercial refrigeration

For more detailed information on the NSS, go to http://www.nssb.org.

Customer Relations

Customer relations are extremely important to a service business and consequently to a service technician. Without customers there will be no business and no income. The technician is a major factor in acquiring and keeping customers. This is true whether work is performed at a residence, an office, a restaurant, or a store, or whether the technician is an inside or outside salesperson for a distributor or contractor. The HVACR business and technician are dependent on the customers. All technicians should be concerned with the quality of their work because customers have the right to insist on quality. If they have had a previous unsatisfactory experience, customers may have some doubt as to whether they will get the quality service for which they are paying. As professionals, technicians should strive to provide the best workmanship possible. Quality work will prove beneficial to the technician, to the company, and to the consumer. Customers depend on the technician for their comfort and air quality at home and at the office.

First Impressions. The impression the technician makes on the customer is very important, and the **first impression** is the most important. The first impression begins with the technician **arriving on time.** Most customers feel that their time is valuable. If the technician is going to be delayed, the customer should be called and given an explanation. An appointment should be scheduled for either later that day or another time convenient for the customer. The customer affected by a delay should be given priority in scheduling a makeup appointment. If the service call is an emergency, all efforts should be made to arrive as soon as possible.

When arriving, **do not park in or block the customer's driveway** unless necessary. If carrying equipment or having to make several trips to the vehicle, ask permission to park in the driveway. The customer may suggest another location. **Ensure that the service vehicle is kept in a neat, clean, and orderly manner.** This will help to make a good impression and provide better working conditions for the technician.

Remember the customer's name and use it frequently, preferably with Ms., Mrs., or Mr. *Sir* or *Ma'am* may also be used when appropriate. When meeting a customer, be prepared to **shake hands.** In many cases it may be appropriate to let the customer initiate the handshake. Your handshake should be firm and accompanied with a smile. A handshake that is too limp may give the impression of weakness; one that is too strong may indicate an overbearing type of person. Not all people like to shake hands. The technician should be friendly and always have a smile.

Appearance. Another major factor in first impressions and maintaining good customer relations is **appearance.** Included is the following:

Hair—brushed or combed, neatly trimmed. Male technicians should be clean shaven or have a neatly trimmed beard or mustache. Female technicians with longer hair may wish to contain it in a ponytail.

Clothing—neat and clean. For most uniforms, ensure that the shirttail is tucked in. A clean and neat uniform will help to make the appropriate presentation. If you have an ID badge, wear it in plain sight.

Personal hygiene—Cleanliness is important. Hands should be washed and clean. A shower before going to bed or before going to work should be a regular habit. Your appearance and personal hygiene are major indicators of your personality and the quality of work you offer.

After arriving at the customer's address take a minute or two to get organized. You may have a clipboard with material to organize and review. Think about what you are going to say and do when meeting the customer. Do not flip a cigarette butt to the ground outside the truck or on the way to the house or other location. There should be **no smoking** while making the service call.

After arriving at the house but before entering, put on your shoe covers.

Do not use the customer's phone for personal calls, and do not use the customer's bathroom.

Communication Skills. The technician must be able to describe the service that can be provided. However, the technician must not monopolize the conversation. A big part of communicating is **listening.** Most people like to be listened to and the more you listen to the customer about the problems involved with the system, the easier it will be to diagnose. **Courtesy** and a **show of respect** for the customer should be evident at all times. The training and high skill level of the technician should also be evident as a result of the conversation and being able to answer and ask questions. Telling people how capable and skilled you are is often a turnoff. Remember to smile often. Ask pertinent questions and do not interrupt when the customer is answering. **Never say anything to discredit a competing business.**

Conflicts and Arguments. Conflicts and arguments with customers should be avoided at all costs. When you are dealing with an angry customer, you are dealing with an emotional customer. Listen until the customer is finished before replying. A complaint may be an opportunity to solve a problem. The customer should feel assured that the technician is competent and that the work will be done properly and in a timely manner. Never be **critical** of a customer, even in a joking manner. People hate to be criticized. It is very important to be friendly.

Even when angry, most customers are good individuals. They may have had a bad experience or may be disappointed, frustrated, and upset. Angry customers may have reviewed what they want to say and will not feel right until they have said it to a willing listener. Be sympathetic, listen carefully, and try to determine why the customer is so upset. Do not take it personally. Do not reply until the customer is definitely finished with the complaint and then try to concentrate on the solution. Ask the customer what you as the technician can do to help resolve the problem. If you can resolve the problem, do it. If you must report it to your supervisor, let the customer know that you will do this right away and will get back to them immediately if possible.

After listening carefully to the customer and resolving any complaint to the extent possible, you should be ready to start the troubleshooting process.

The Service Call. After arriving and introducing yourself, it is important to ask as many questions as needed to have a clear understanding of the problem. These questions will help to assure the customer that you are capable of solving the problem. During the service procedure you may need to talk with the customer to explain what you have found and to indicate the parts needed and possibly state the approximate costs if they may be higher than expected. If you must leave the job for any reason,

tell the customer the reason and when you will return. You may need to go for parts or to another job emergency, but the customer needs to be informed. An informed customer is less likely to become angry or to complain. Keep the customer informed of all unusual circumstances. Double-check all your work. Clean the work site when finished and protect the customer's property from damage.

After the service work is completed, tell the customer what you found to be wrong, indicate that it has been corrected, and demonstrate when possible by turning the unit on while explaining how the problem was corrected. Customers deserve to know what they are paying for. All discussions should be in terms the customer will understand. Before leaving, billing information should be given to the customer. This should include a description of the work done and the costs.

The Technician as a Salesperson. A good technician is also a good salesperson. All options to resolve a problem should be presented in an honest and fair manner. Provide estimates and work orders in writing. A customer is buying not only service or equipment but also a solution to a problem. The customer may be offered an option not necessarily needed but should not be "talked into it." The sale and installation of a new system is not always the best option for a customer. If a customer feels that he or she was talked into something that was not needed, there is a good chance that the transaction will end the relationship between the customer and the company.

A company may have written recommendations for guiding the technician in presenting options. For instance if a unit is "x" years old and the repair will cost "x" amount, a recommendation to replace the unit or system may be appropriate.

In summary:

First impressions are very important.

Appearance and personal hygiene are major indicators of your personality and the quality of work you offer.

As a technician, you must be a good communicator.

Conflicts and arguments with customers should be avoided at all costs.

When making a service call, ask as many questions as needed to have a clear understanding of the problem.

If you must leave the job site, tell the customer why you are leaving and when you will return.

As a salesperson, you should be honest and fair to the customer, to yourself, and to your employer.

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SECTION 1

Theory of Heat

UNIT 1 Heat and Pressure

OBJECTIVES

After studying this unit, you should be able to

- define temperature.
- make conversions between Fahrenheit and Celsius scales.
- describe molecular motion at absolute zero.
- define the British thermal unit.
- describe heat flow between substances of different temperatures.
- explain the transfer of heat by conduction, convection, and radiation.
- discuss sensible heat, latent heat, and specific heat.
- state atmospheric pressure at sea level and explain why it varies at different elevations.
- describe two types of barometers.
- explain psig and psia as they apply to pressure measurements.

Figure 1–1 These are the tools of our trade; they are used to measure temperature and pressure.

1.1 HOW WE USE HEAT AND PRESSURE

The term *heat* can be applied to events in our lives that refer to our comfort, food, weather, and many other things. How does *cold* figure in? Cold will be discussed later as the absence of heat. We say, "It is hot outside," or "The coffee is hot; the ice cream is cold." In the field of refrigeration and air-conditioning technology, we must really understand what heat is and how it works for or against us and be able to explain it to other people.

Pressure is another term that we use in our everyday lives that must be understood. We talk about atmospheric pressure when we talk about the weather. We talk about tire pressure on our bikes and cars.

Both of these terms, temperature and pressure, will be used daily in conversation about our industry. **Figure 1–1** shows the instruments that we will use to measure temperature and pressure.

1.2 TEMPERATURE

Temperature can be thought of as a description of the level of heat and also may be referred to as heat intensity. Both heat level and heat intensity should not be confused with the amount of heat, or heat content. Heat can also be thought of as energy in the form of molecules in motion. Everything in the universe is made up of molecules. A molecule is the smallest portion that an element or substance can be divided into. For example, we all know that water is made of hydrogen and oxygen (H_2O), which is two molecules of hydrogen and one molecule of oxygen combined together. All of these molecules vibrate and create heat while vibrating. The starting point of temperature is, therefore, the starting point of molecular motion.

Most people know that the freezing point of water is 32 degrees Fahrenheit (32°F) and that the boiling point is 212 degrees Fahrenheit (212°F), **Figure 1–2.** These points are commonly indicated on a thermometer, which is an instrument that measures temperature.

Early thermometers were of glass-stem types and operated on the theory that when the substance in the bulb was heated it would expand and rise in the tube, **Figure 1–3.** Mercury and alcohol are still commonly used today for this application.

We must qualify the statement that water boils at 212°F. Pure water boils at 212°F when standard atmospheric conditions exist. Standard conditions are sea level with the barometer reading 29.92 in. Hg (14.696 psia). This qualification concerns the relationship of the earth's atmosphere to the boiling point and will be covered in detail later in this section in the discussion on pressure. The statement that water boils at 212°F at standard conditions is important because these are standard conditions that will be applied to actual practice in later units.

Pure water has a freezing point of 32°F. Obviously the temperature can go lower than 32°F, but the question is, how much lower?

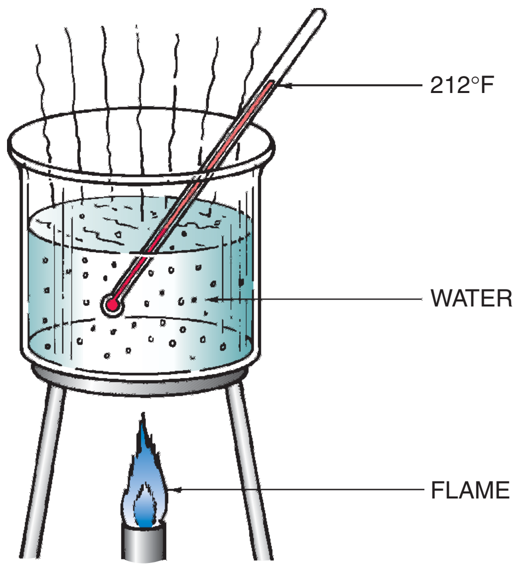


Figure 1–2 The water in the container increases in temperature because the molecules move faster as heat is applied. When the water temperature reaches 212°F, boiling will occur. The bubbles in the water are small steam cells that are lighter than water and rise to the top.

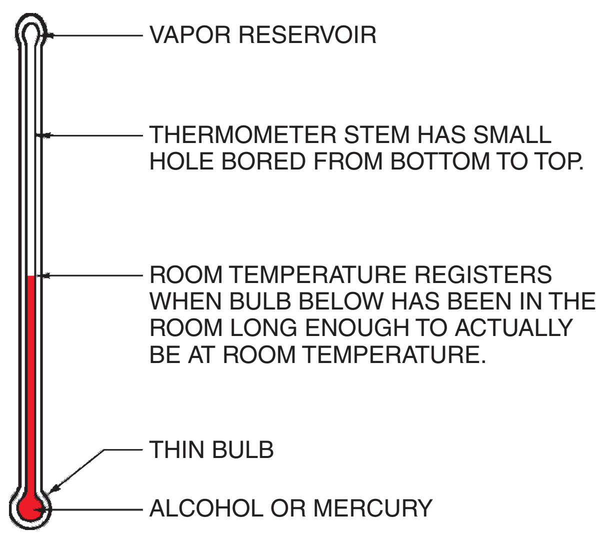


Figure 1–3 A glass stem thermometer.

The theory is that molecular motion stops at −460°F. This is theoretical because molecular motion has never been totally stopped. The complete stopping of molecular motion is expressed as absolute zero. This has been calculated to be −460°F. Scientists have actually come within a few degrees of causing substances to reach absolute zero. **Figure 1–4** is an illustration of some levels of heat (molecular motion) shown on a thermometer scale.

The Fahrenheit scale of temperature is used in the English measurement system by the United States, one of only a few countries in the world that uses this system. The Celsius scale of temperature measurement is used in the International System of Units (SI) or *metric* system used by most other countries.

As the United States develops trade opportunities with the rest of the world, it may become necessary to use the metric

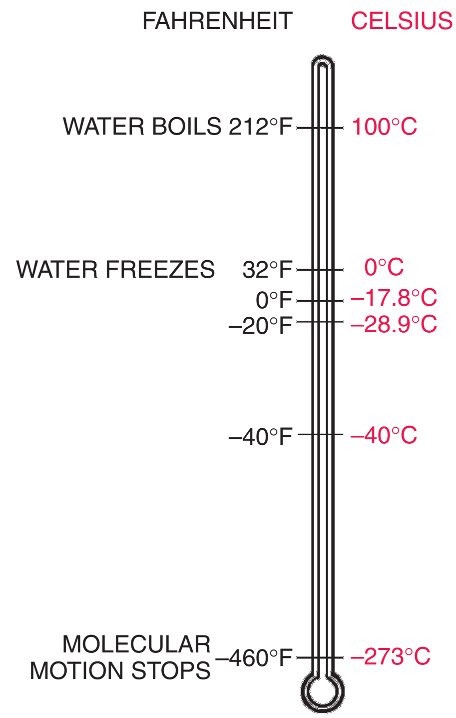


Figure 1–4 Fahrenheit scale compared with Celsius scale.

system. **Figure 1–4** illustrates a thermometer with some important Fahrenheit and Celsius equivalent temperatures. **Figure 1–5** illustrates a thermometer showing more equivalent temperatures. See the Temperature Conversion Table in the appendix for conversion of temperatures. Formulas can also be used to make conversions. Use of the table and formulas is discussed at the end of this unit.

Most of the terms of measurement in this book are in English terms because at this time these are the terms most often used by technicians in this industry in the United States.

Temperature has been expressed in everyday terms up to this point. It is equally important in the air-conditioning, heating, and refrigeration industry to describe temperature in terms engineers and scientists use. Performance ratings of equipment are established using *absolute* temperature. Equipment is rated to establish criteria for comparing equipment performance. Using these ratings, different manufacturers can make comparisons with other manufacturers regarding their products. We can use the equipment rating to evaluate these comparisons. The Fahrenheit absolute scale is called the *Rankine* scale (named for its inventor, W. J. M. Rankine), and the Celsius absolute scale is known as the *Kelvin* scale (named for the scientist Lord Kelvin). Absolute temperature scales begin where molecular motion starts; they use 0 as the starting point. For instance, 0 on the Fahrenheit absolute scale is called absolute zero or 0° Rankine (0°R). Similarly, 0 on the Celsius absolute scale is called absolute zero or 0 Kelvin (0°K), **Figure 1–6.**

The Fahrenheit/Celsius and the Rankine/Kelvin scales are used interchangeably to describe equipment and fundamentals of this industry. Memorization is not required. A working knowledge of these scales and conversion formulas

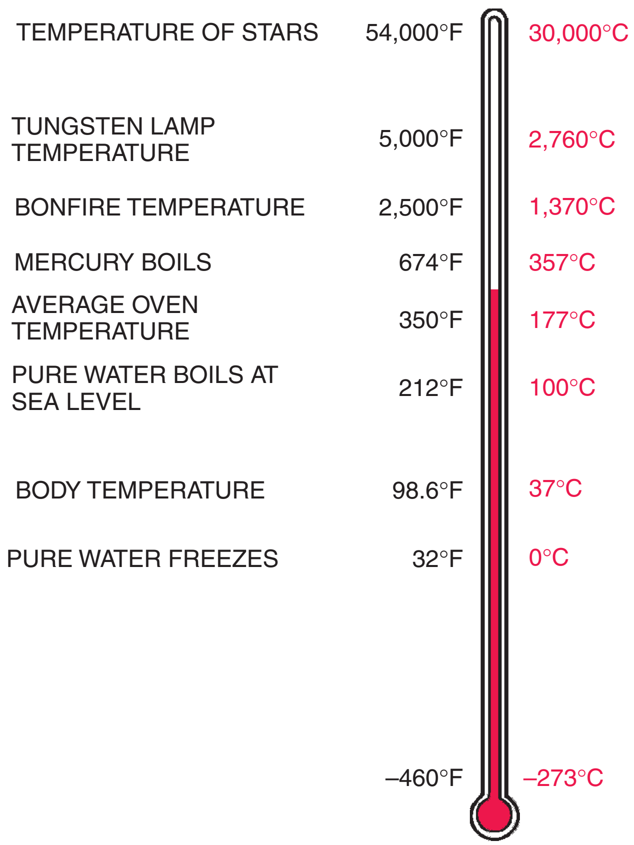


Figure 1–5 Civilization is generally exposed to a comparatively small range of temperatures.

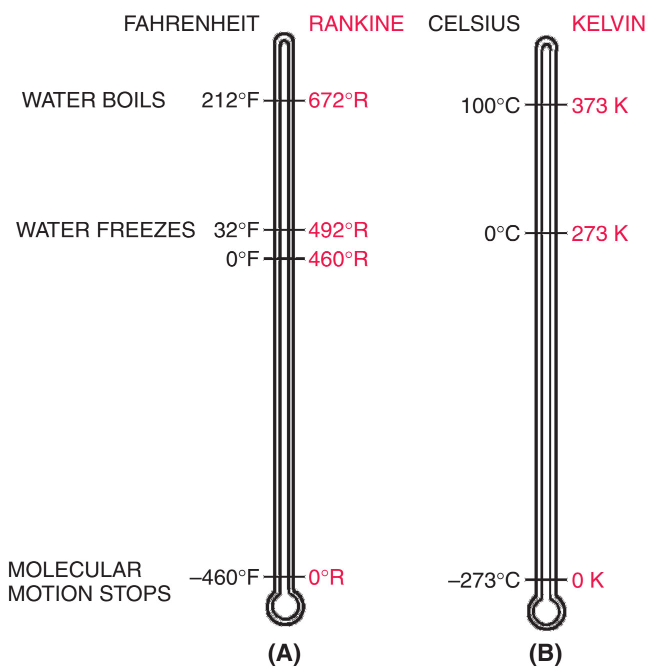


Figure 1–6 **(A)** A Fahrenheit and Rankine thermometer. **(B)** A Celsius and Kelvin thermometer.

and a ready reference table are more practical. **Figure 1–6** shows how these four scales are related. The world we live in accounts for only a small portion of the total temperature spectrum.

Our earlier statement that temperature describes the level of heat, heat intensity, or molecular motion can now be explained. As a substance receives more heat, its molecular motion, and therefore its temperature, increases, **Figure 1–2.**

1.3 INTRODUCTION TO HEAT

The laws of thermodynamics can help us to understand what heat is all about. One of these laws states that energy can be neither created nor destroyed, but can be converted from one form to another. This means that most of the heat the world experiences is not being continuously created but is being converted from other forms of energy like fossil fuels (gas and oil). This heat can also be accounted for when it is transferred from one substance to another.

Temperature describes the level of heat with reference to no heat. The term used to describe the quantity of heat or heat content is known as the *British thermal unit (Btu).* This term explains how much heat is contained in a substance. The rate of heat consumption can be determined by adding time.

The Btu is defined as the amount of heat required to raise the temperature of 1 lb of water 1°F. For example, when 1 lb of water (about 1 pint) is heated from 68°F to 69°F, 1 Btu of heat energy is absorbed into the water, **Figure 1–7.** To actually measure how much heat is absorbed in a process like this, we need an instrument of laboratory quality. This instrument is called a *calorimeter.* Notice the similarity to the word "calorie," the food word for energy.

When a temperature difference exists between two substances, heat transfer will occur. Temperature difference is the driving force behind heat transfer. The greater the temperature difference, the greater the heat transfer rate. Heat flows naturally from a warmer substance to a cooler substance. Rapidly moving molecules in the warmer substance give up some of their energy to the slower moving molecules in the cooler substance. The warmer substance cools because the molecules have slowed. The cooler substance becomes warmer because the molecules are moving faster.

The following example illustrates the difference in the quantity of heat compared with the level of heat. One tank of water weighing 10 lb (slightly more than 1 gallon [gal]) is heated to a temperature level of 200°F. A second tank of water weighing 100,000 lb (slightly more than 12,000 gal) is heated to 175°F. The 10-lb tank will cool to room temperature much faster than the 100,000-lb tank. The temperature difference of 25°F is not much, but the cool-down time is much longer for the 100,000-lb tank due to the quantity of water, **Figure 1–8.**

A comparison using water may be helpful in showing the heat intensity level versus the quantity of heat. A 200-ft deep well would not contain nearly as much water as a large lake with a water depth of 25 ft. The depth of water (in feet) tells us the level of water, but it in no way expresses the quantity (gallons) of water.

In practical terms, each piece of heating equipment is rated according to the amount of heat it will produce. If the equipment had no such rating, it would be difficult for a buyer to intelligently choose the correct appliance.

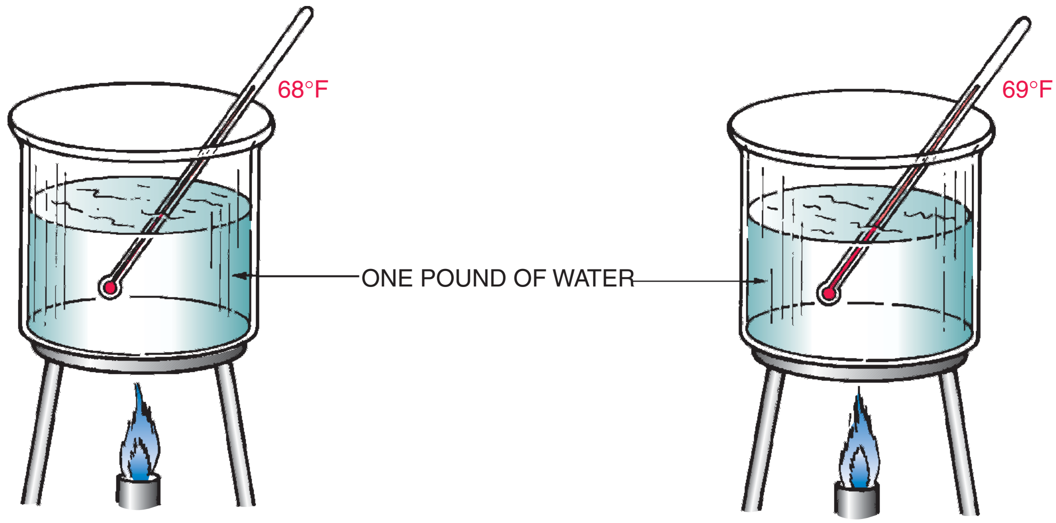


Figure 1–7 One British thermal unit (Btu) of heat energy is required to raise the temperature of 1 lb (pound) of water from 68°F to 69°F.

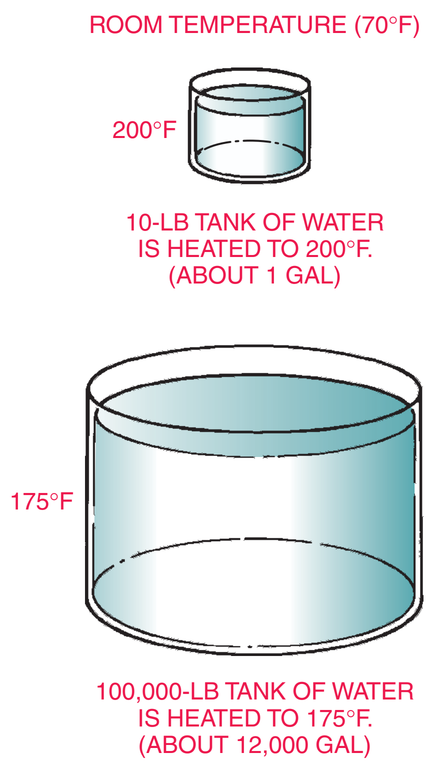


Figure 1–8 The smaller tank will cool to room temperature first because a smaller quantity of heat exists, even though its temperature or heat intensity level is higher.

A gas or oil furnace used to heat a home has the rating permanently printed on a nameplate. Either furnace would be rated in Btu per hour, which is a *rate* of energy consumption. Later, this rate will be used to calculate the amount of fuel required to heat a house or a structure. For now, it is sufficient to say that if one needs a 75,000-Btu/h furnace to heat a house on the coldest day, a furnace rated at 75,000 Btu/h should be chosen. If not, the house will begin to get cold any time the heat loss of the house exceeds the furnace output in Btu/h.

In the metric, or SI, system of measurement, the term *joule (J)* is used to express the quantity of heat. Because a joule is very small, metric units of heat in this industry are usually expressed in kilojoules (kJ) or 1000 joules. One Btu equals 1.055 kJ.

The term *gram (g)* is used to express weight in the metric system. Again, this is a small quantity of weight, so the term kilograms (kg) is often used. One pound equals 0.45359 kg.

The amount of heat required to raise the temperature of 1 kg of water 1°C is equal to 4.187 kJ.

Cold is a comparative term used to describe lower temperature levels. Because all heat is a positive value in relation to no heat, cold is not a true value. It is really an expression of comparison. When a person says it is cold outside, it is in relation to the normal expected temperature for the time of year or to the inside temperature. Cold has no number value and is used by most people as a basis of comparison only. Cold is sometimes referred to as a level of heat absence.

1.4 CONDUCTION

Conduction heat transfer can be explained as the energy actually traveling from one molecule to another. As a molecule moves faster, it causes others to do the same. For example, if one end of a copper rod is in a flame, the other end gets too hot to handle. The heat travels up the rod from molecule to molecule, **Figure 1–9.**

Conduction heat transfer is used in many heat transfer applications that are experienced regularly. Heat is transferred by conduction from the hot electric burner on the cookstove to the pan of water. It then is transferred by conduction into the water. Note that there is an orderly explanation for each step.

Heat does not conduct at the same rate in all materials. Copper, for instance, conducts at a different rate from iron. Glass is a very poor conductor of heat.

Touching a wooden fence post or another piece of wood on a cold morning does not give the same sensation as touching a car fender or another piece of steel. The piece of steel

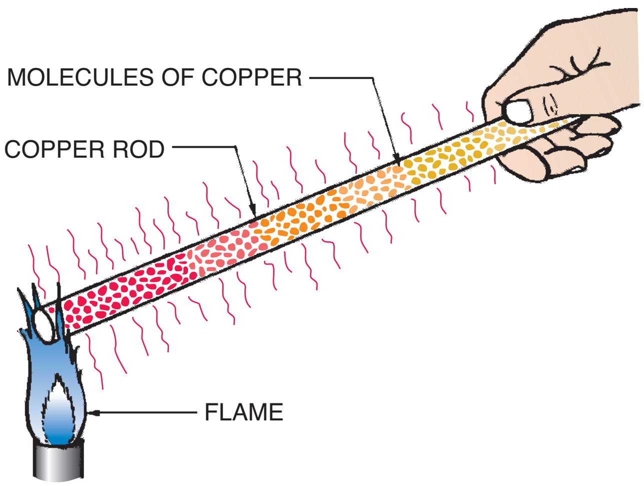


Figure 1–9 The copper rod is held in the flame only for a short time before heat is felt at the far end.

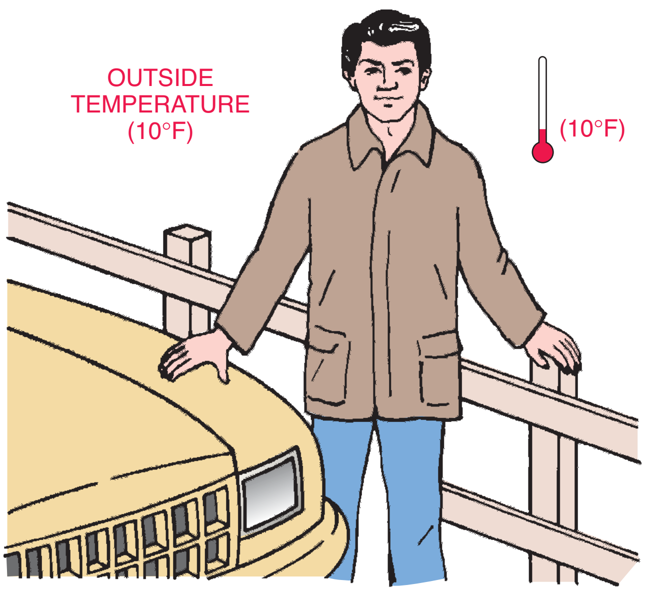


Figure 1–10 The car fender and the fence post are actually the same temperature, but the fender feels colder because the metal conducts heat away from the hand faster than the wooden fence post.

feels much colder. Actually the steel is not colder; it just conducts heat out of the hand faster, **Figure 1–10.**

The different rates at which various materials conduct heat have an interesting similarity to the conduction of electricity. As a rule, substances that are poor conductors of heat are also poor conductors of electricity. For instance, copper is one of the best conductors of electricity and heat, and glass is one of the poorest conductors of both. Glass is actually used as an insulator of electrical current flow.

1.5 CONVECTION

Convection heat transfer is used to move heat from one location to another by means of currents set up in a fluid medium. The most common fluid mediums in the heating and air-conditioning trades are air and water. When heat is moved, it is normally transferred into some substance that is readily movable, such as air or water. Many large buildings have a central heating plant where water is heated and pumped throughout the building to the final heated space. Notice the similarity of the words "convection" and "convey" (to carry from one place to another).

A forced air gas furnace is an example of forced convection. Room air is drawn into the return air of the furnace by the fan. This air is forced out the fan outlet over the furnace heat exchanger, which exchanges heat to the air from a gas flame. The air is then forced into the ductwork and distributed into the various rooms in the structure. **Figure 1–11**

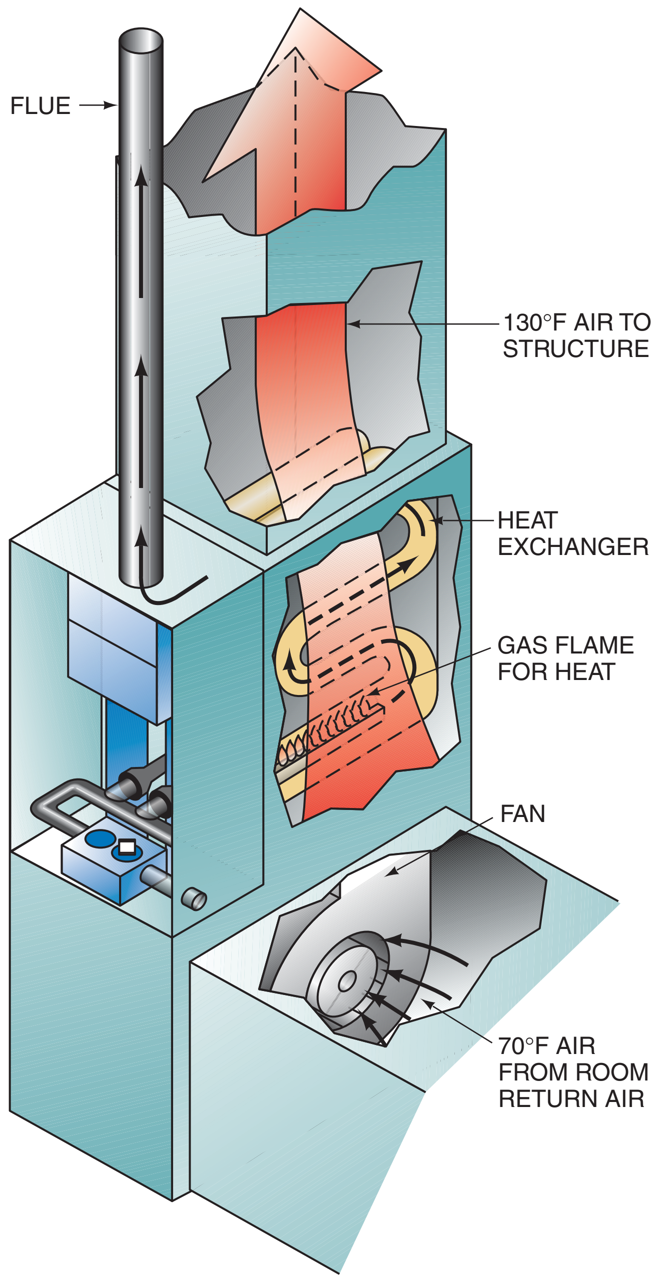


Figure 1–11 Air from the room enters the fan at 70°F. The fan forces the air across the hot heat exchanger and out into the structure at 130°F.

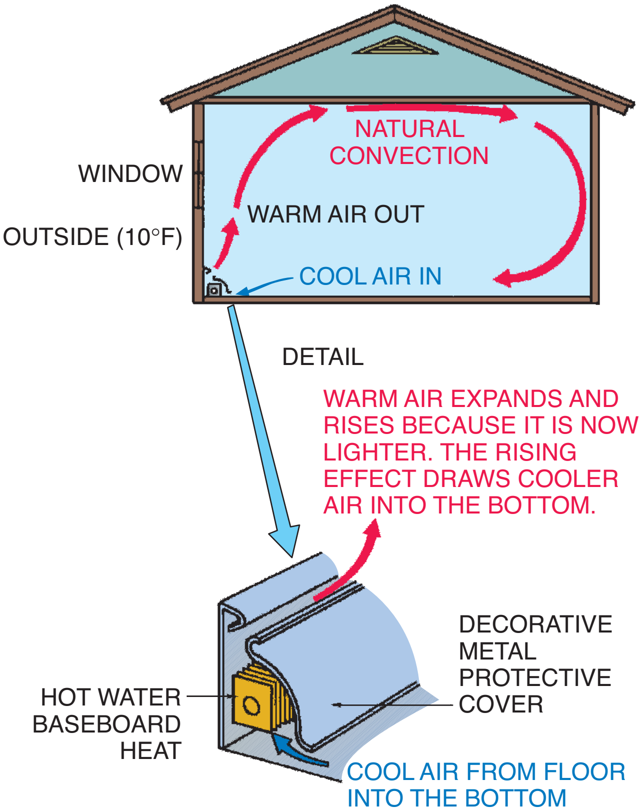


Figure 1–12 Natural convection occurs when heated air rises and cool air takes its place.

shows this process in which 70°F room air is entering the furnace; 130°F air is leaving; and the fan is creating the pressure difference to force the air into the various rooms. The fan provides the *forced convection*.

Another example of heat transfer by convection is that when air is heated, it rises; this is called *natural* convection. When air is heated, it expands, and the warmer air becomes less dense or lighter than the surrounding unheated air. This principle is applied in many ways in the air-conditioning industry. Baseboard heating units are an example. They are normally installed on the outside walls of buildings and use electricity or hot water as the heat source. When the air near the floor is heated, it expands and rises. This heated air is displaced by cooler air around the heater, which sets up a natural convection current in the room, **Figure 1–12.**

1.6 RADIATION

Radiation heat transfer can best be explained by using the sun as an example of the source. The sun is approximately 93 million miles from the earth's surface, yet we can feel its intensity. The sun's surface temperature is extremely hot compared with anything on earth. Heat transferred by radiation travels through space without heating the space and is absorbed by the first solid object that it encounters. Radiation is the only type of heat transfer that can travel through a vacuum, such as space, because radiation is not dependent on matter as a medium of heat transfer. This is impossible with convection and conduction because they require some form of matter, like air or water, to be the transmitting medium. The earth does not experience the total heat of the sun because heat transferred by radiation diminishes by the inverse of the square of the distance traveled. In practical terms, this means that every time the distance is doubled, the heat intensity decreases by one-fourth. If you hold your hand close to a light bulb, for example, you feel the heat's intensity, but if you move your hand twice the distance away, you feel only one-fourth of the heat intensity, **Figure 1–13.** Keep in mind that, because of the inverse-square-of-the-distance explanation, radiant heat does not transfer the actual temperature or heat quantity value. If it did, the earth would be as hot as the sun.

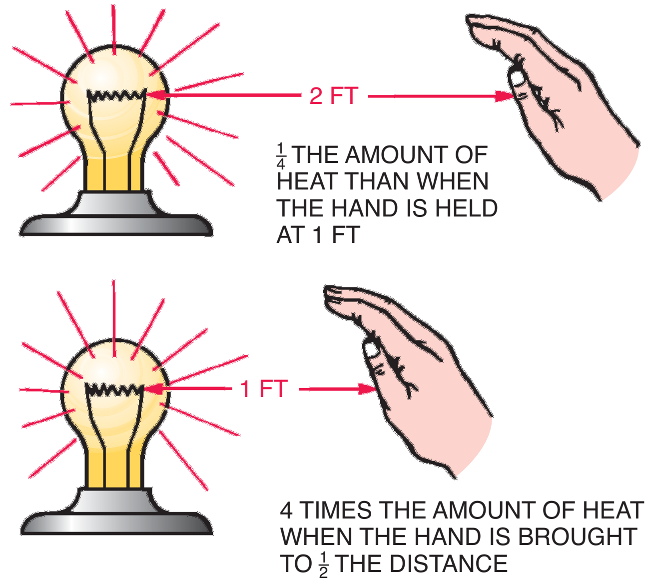


Figure 1–13 The intensity of the radiant heat diminishes by the square of the distance.

Electric heaters that glow red hot are practical examples of radiant heat. The electric heater coil glows red hot and radiates heat into the room. It does not heat the air, but it warms the solid objects that the heat rays encounter. Any heater that glows has the same effect.

1.7 SENSIBLE HEAT

Heat level or heat intensity can readily be measured when it changes the temperature of a substance (remember the example of changing 1 lb of water from 68°F to 69°F). This change in the heat level can be measured with a thermometer. When a change of temperature can be registered, we know that the level of heat or heat intensity has changed; this is called *sensible heat*.

1.8 LATENT HEAT

Another type of heat is called *latent* or *hidden* heat. In this process heat is known to be added, but no temperature rise is noticed. An example is heat added to water while it is

boiling in an open container. Once water is brought to the boiling point, adding more heat only makes it boil faster; it does not raise the temperature, **Figure 1–14.**

The following example describes the sensible heat and latent heat characteristics of 1 lb of water at standard atmospheric pressure. These are explored from 0°F through the temperature range to above the boiling point. Examine the chart in **Figure 1–15** and notice that temperature is plotted on the left margin, and heat content is plotted along the bottom of the chart. We see that as heat is added the temperature will rise except during the latent- or hidden-heat process. This chart is interesting because heat can be added without causing a rise in temperature.

The following statements should help you to understand the chart.

1. Water is in the form of ice at point 1 where the example starts. Point 1 is *not* absolute zero. It is 0°F and is used as a point of departure.
2. Heat added from point 1 to point 2 is sensible heat. This is a registered rise in temperature. Note that it only takes 0.5 Btu of heat to raise 1 lb of ice 1°F. We know this because it took only 16 Btu of sensible heat to raise the temperature from 0°F to 32°F.
3. When point 2 is reached, the ice is at its highest temperature of 32°F. This means that if more heat is added, it will be known as latent heat and will start to

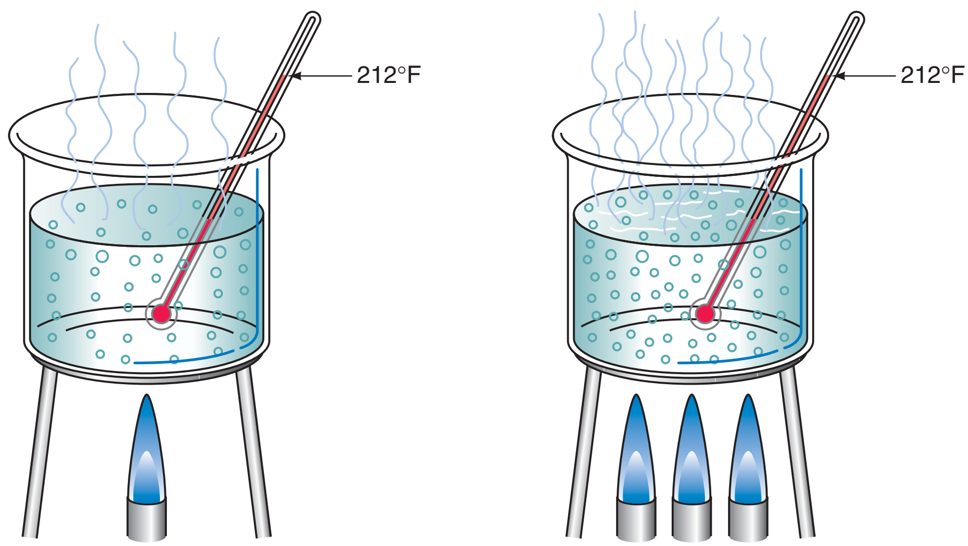


Figure 1–14 Adding three times as much heat only causes the water to boil faster. The water does not increase in temperature.

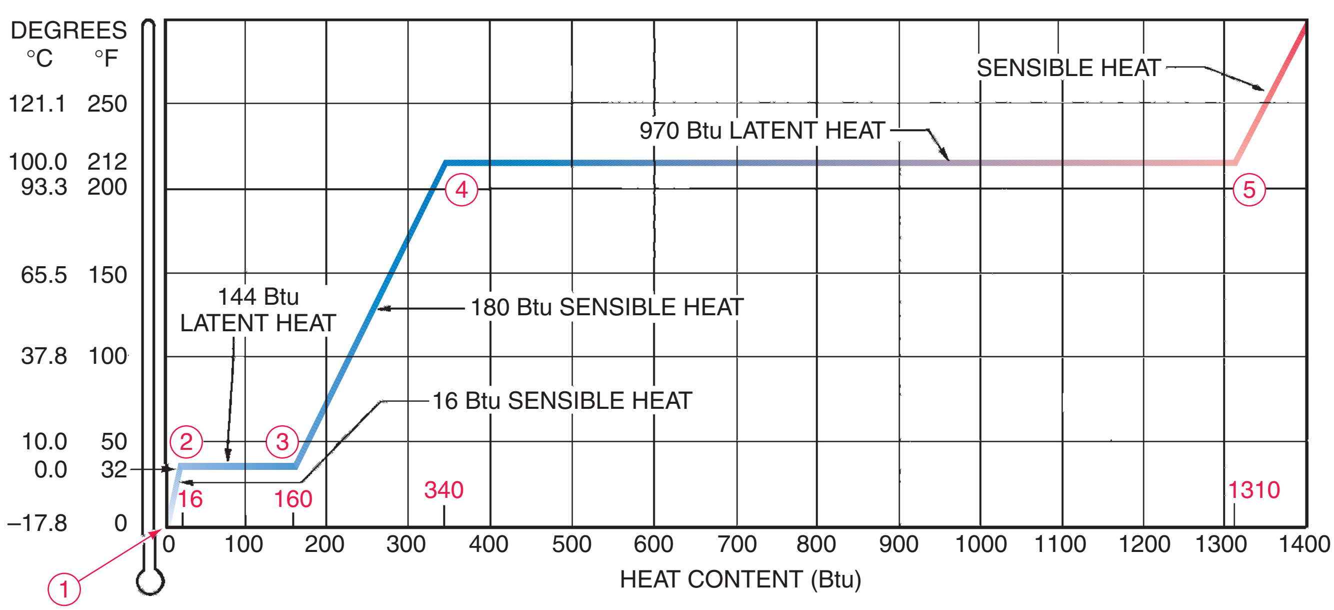


Figure 1–15 The heat/temperature graph for 1 lb of water at atmospheric pressure explains how water responds to heat. An increase in sensible heat causes a rise in temperature. An increase in latent heat causes a change of state, for example, from solid ice to liquid water.

SUBSTANCE	SPECIFIC HEAT Btu/lb/°F	SUBSTANCE	SPECIFIC HEAT Btu/lb/°F
ALUMINUM	0.224	BEETS	0.90
BRICK	0.22	CUCUMBERS	0.97
CONCRETE	0.156	SPINACH	0.94
COPPER	0.092	BEEF, FRESH	
ICE	0.504	LEAN	0.77
IRON	0.129	FISH	0.76
MARBLE	0.21	PORK, FRESH	0.68
STEEL	0.116	SHRIMP	0.83
WATER	1.00	EGGS	0.76
SEA WATER	0.94	FLOUR	0.38
AIR	0.24 (AVERAGE)		

Figure 1–16 The specific heat table shows how much heat is required to raise the temperature of several different substances 1°F.

melt the ice but not raise the temperature. Adding 144 Btu of heat will change the 1 lb of ice to 1 lb of water. Removing any heat will cool the ice below 32°F.

4. When point 3 is reached, the substance is now 100% water. Adding more heat causes a rise in temperature. (This is sensible heat.) Removal of any heat at point 3 results in some of the water changing back to ice. This is known as removing latent heat because there is no change in temperature.
5. Heat added from point 3 to point 4 is sensible heat; when point 4 is reached, 180 Btu of heat will have been added from point 3: 1 Btu/lb/°F temperature change for water.
6. Point 4 represents the 100% saturated liquid point. The water is saturated with heat to the point that the removal of any heat causes the liquid to cool off below the boiling point. Heat added is identified as latent heat and causes the water to boil and to start changing to a vapor (steam). Adding 970 Btu makes the 1 lb of liquid boil to point 5 and become a vapor.
7. Point 5 represents the 100% saturated vapor point. The water is now in the vapor state. Heat removed would be latent heat and would change some of the vapor back to a liquid. This is called *condensing the vapor.* Any heat added at point 5 is sensible heat; it raises the vapor temperature above the boiling point. Heating the vapor temperature above the boiling point is called *superheating.* Any water vapor with a temperature above the boiling point of 212°F is called a superheated vapor in this example. Superheat will be important in future studies. Note that in the vapor state it takes only 0.5 Btu to heat the water vapor (steam) 1°F. The same was true while water was in the ice (solid) state.

SAFETY PRECAUTION: When examining these principles in practice, be careful because the water and steam are well above body temperature, and you could be seriously burned.

1.9 SPECIFIC HEAT

We now realize that different substances respond differently to heat. When 1 Btu of heat energy is added to 1 lb of water, it changes the temperature 1°F. This only holds true for water. When other substances are heated, different values occur. For instance, we noted that adding 0.5 Btu of heat energy to either ice or steam (water vapor) caused a 1°F rise per pound while in these states. They heated, or increased the temperature, at twice the rate. Adding 1 Btu would cause a 2°F rise. This difference in heat rise is known as *specific heat.*

Specific heat is the amount of heat necessary to raise the temperature of 1 lb of a substance 1°F. Every substance has a different specific heat. Note that the specific heat of water is 1 Btu/lb/°F. See **Figure 1–16** for the specific heat of some other substances.

1.10 SIZING HEATING EQUIPMENT

Specific heat is significant because the amount of heat required to change the temperatures of different substances is used to size equipment. Recall the example of the house and furnace earlier in this unit.

The following example shows how this would be applied in practice. A manufacturing company may need to buy a piece of heating equipment to heat steel before it can be machined. The steel may be stored outside in the cold at 0°F and need preheating before machining. The temperature desired for the machining is 70°F. How much heat must be added to the steel if the plant wants to machine 1000 lb/h?

The steel is coming into the plant at a fixed rate of 1000 lb/h, and that heat has to be added at a steady rate to stay ahead of production. **Figure 1–16** gives a specific heat of 0.116 Btu/lb/°F for steel. This means that 0.116 Btu of heat energy must be added to 1 lb of steel to raise its temperature 1°F.

$$Q = \text{Weight} \times \text{Specific Heat} \times \text{Temperature Difference}$$

where Q = quantity of heat needed. Substituting in the formula, we get

$$Q = 1000\ \text{lb/h} \times 0.116\ \text{Btu/lb/°F} \times 70\text{°F}$$

$$Q = 8120\ \text{Btu/h required to heat the steel for machining.}$$

The previous example has some known values and a value to be found. The known information is used to find the unknown value with the help of the formula. The formula can be used when adding heat or removing heat and is often used in heat-load calculations for sizing both heating and cooling equipment.

1.11 PRESSURE

Pressure is defined as force per unit of area. This is normally expressed in pounds per square inch (psi). Simply stated, when a 1-lb weight rests on an area of 1 square inch (1 in^2), the pressure exerted downward is 1 psi. Similarly, when a 100-lb weight rests on a 1-in^2 area, 100 psi of pressure is exerted, **Figure 1–17.**

When you swim below the surface of the water, you feel a pressure pushing inward on your body. This pressure is caused by the weight of the water and is very real. A different sensation is felt when flying in an airplane without a pressurized cabin. Your body is subjected to less pressure instead of more, yet you still feel uncomfortable.

It is easy to understand why the discomfort under water exists. The weight of the water pushes in. In the airplane, the reason is just the reverse. There is less pressure high in the air than down on the ground. The pressure is greater inside your body and is pushing out.

Water weighs 62.4 pounds per cubic foot (lb/ft^3). A cubic foot (7.48 gal) exerts a downward pressure of 62.4 lb/ft^2 when it is in its actual cube shape, **Figure 1–18.** How much weight is then resting on 1 in^2? The answer is simply calculated. The bottom of the cube has an area of 144 in^2 (12 in. × 12 in.) sharing the weight. Each square inch has a total pressure of 0.433 lb (62.4 ÷ 144) resting on it. Thus, the pressure at the bottom of the cube is 0.433 psi, **Figure 1–19.**

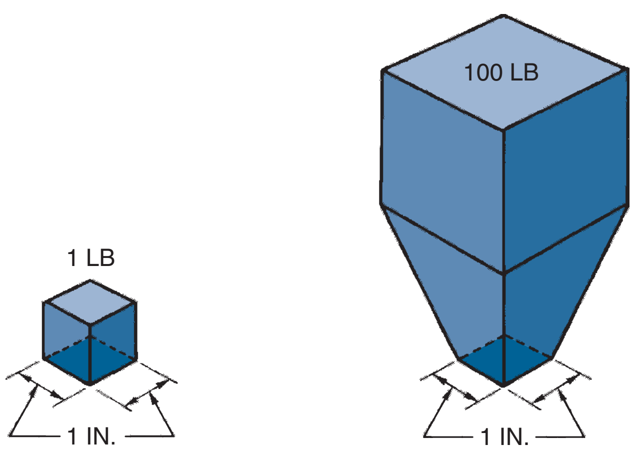


Figure 1–17 Both weights are resting on a 1-square-inch (1-in^2) surface. One weight exerts a pressure of 1 psi, the other a pressure of 100 psi.

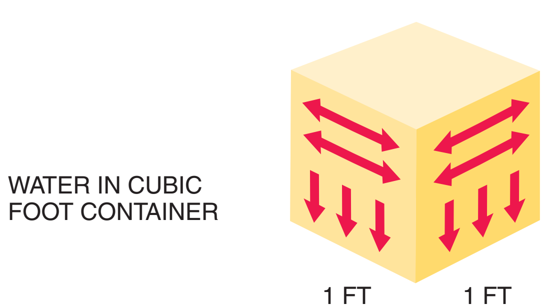


Figure 1–18 One cubic foot (1 ft^3) of water (7.48 gal) exerts its pressure outward and downward. 1 ft^3 of water weighs 62.4 lb spread over 1 ft^2.

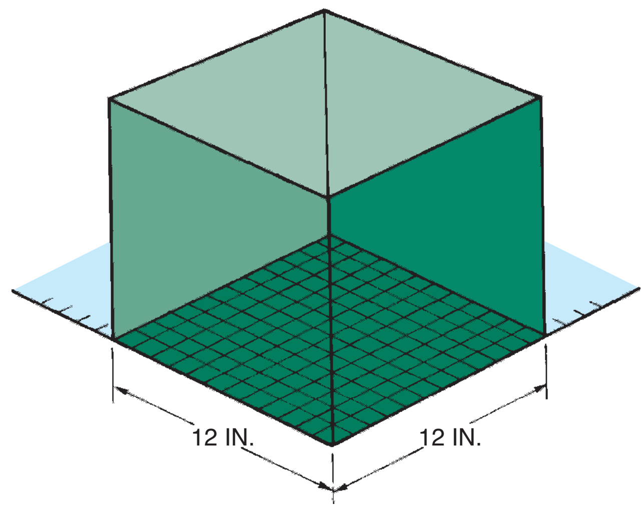


Figure 1–19 One cubic foot (1 ft^3) of water exerts a downward pressure of 62.4 lb/ft^2 on the bottom surface area of a cube.

1.12 ATMOSPHERIC PRESSURE

The sensation of being underwater and feeling the pressure of the water is familiar to many people. The earth's atmosphere is like an ocean of air that has weight and exerts pressure. The earth's surface can be thought of as being at the bottom of this ocean of air. Different locations are at different depths. For instance, there are sea-level locations such as Miami, Florida, or mountainous locations such as Denver, Colorado. The atmospheric pressures at these two locations are different. For now, we will assume that we live at the bottom of this ocean of air.

The atmosphere that we live in has weight just as water does, but not as much. Actually the earth's atmosphere exerts a weight or pressure of 14.696 psi at sea level. This is known as a standard condition.

Atmospheric pressure can be measured with an instrument called a *barometer.* The barometer is a glass tube about 36 in. long that is closed on one end and filled with mercury. It is then inserted open-side down into a puddle of mercury and held upright. The mercury will try to run down into the puddle, but it will not all run out. The atmosphere is pushing down on the puddle, and a vacuum is formed in the top of the tube. The mercury in the tube will fall to 29.92 in. at sea level when the surrounding atmospheric temperature is 70°F, **Figure 1–20.** This is a standard that is used for comparison in engineering and scientific work. If the barometer is taken up higher, such as on a mountain, the mercury column will start to fall. It will fall about 1 in./1000 ft of altitude. When the barometer is at standard conditions and the mercury drops, it is called a low-pressure system by the weather forecaster; this means the weather is going to change. Listen closely to the weather report, and the weather forecaster will make these terms more meaningful.

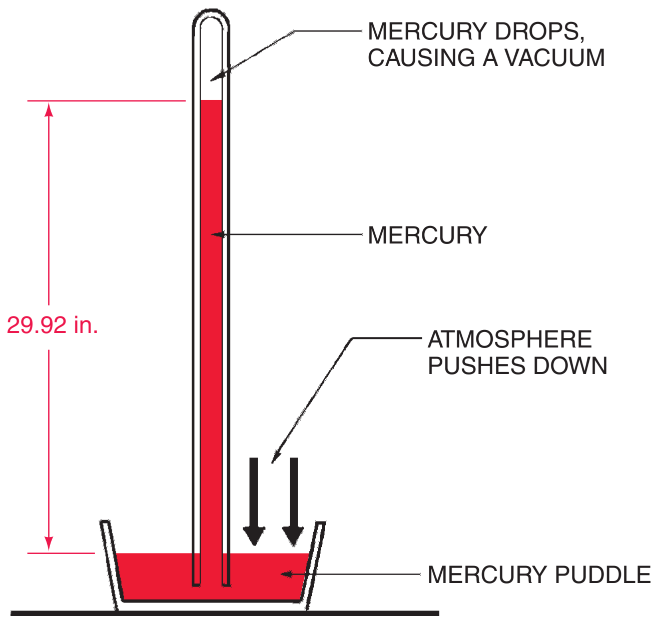


Figure 1–20 Mercury (Hg) barometer.

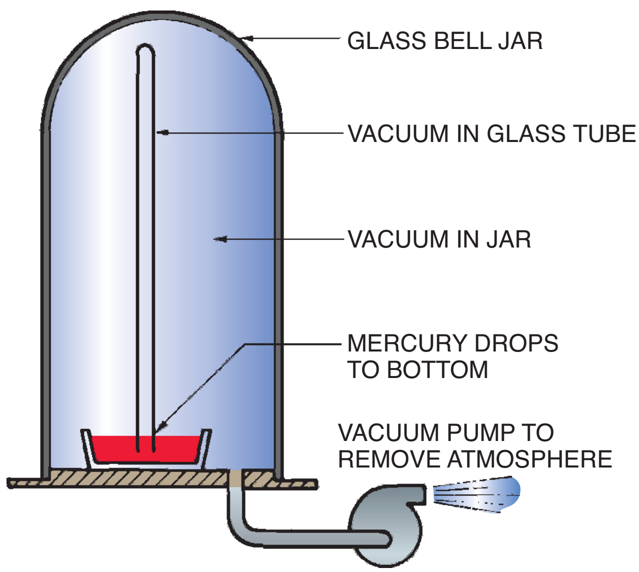


Figure 1–21 When the mercury barometer is placed in a closed glass jar (known as a bell jar) and the atmosphere is removed from the jar, the column of mercury drops to the level of the puddle in the dish.

If the barometer is placed inside a closed jar and the atmosphere evacuated, the mercury column falls to a level with the puddle in the bottom, **Figure 1–21.** When the atmosphere is allowed back into the jar, the mercury again rises because a vacuum exists above the mercury column in the tube.

The mercury in the column has weight and counteracts the atmospheric pressure of 14.696 psi at standard conditions. A pressure of 14.696 psi then is equal to the weight of a column of mercury (Hg) 29.92 in. high. The expression "inches of mercury" thus becomes an expression of pressure and can be converted to pounds per square inch. The conversion factor

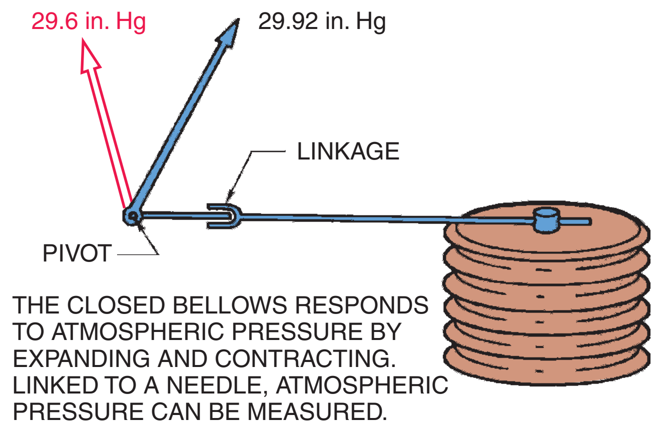


Figure 1–22 The aneroid barometer uses a closed bellows that expands and contracts with atmospheric pressure changes.

is 1 psi = 2.036 in. Hg (29.92 ÷ 14.696); 2.036 is often rounded off to 2 (30 in. Hg ÷ 15 psi).

Another type of barometer is the *aneroid* barometer. This is a more practical instrument to transport. Atmospheric pressure has to be measured in many places, so instruments other than the mercury barometer had to be developed for field use, **Figure 1–22.**

1.13 PRESSURE GAGES

Measuring pressures in a closed system requires a different method—the Bourdon tube, **Figure 1–23.** The *Bourdon tube* is linked to a needle and can measure pressures above and below atmospheric pressure. A common tool used in the refrigeration industry to take readings in the field or shop is a combination of a low-pressure gage (called the *low-side gage*) and a high-pressure gage (called the *high-side gage*),

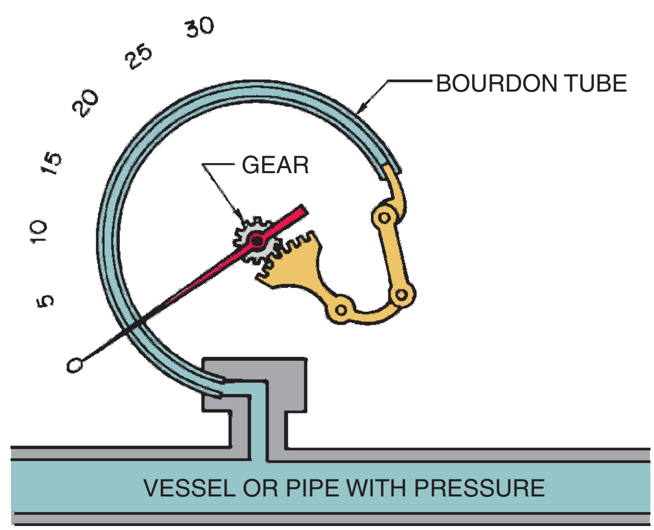


Figure 1–23 The Bourdon tube is made of a thin substance such as brass. It is closed on one end, and the other end is fastened to the pressure being checked. When pressure increases, the tube tends to straighten out. When attached to a needle linkage, pressure changes are indicated.

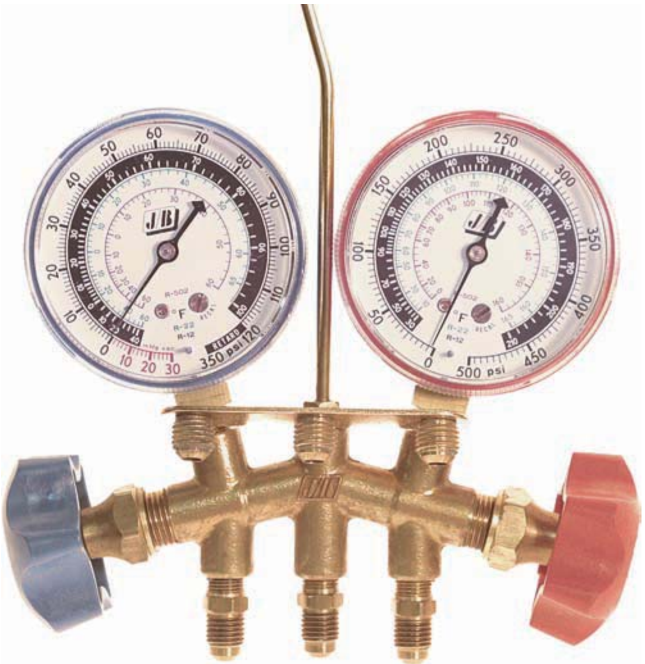


Figure 1–24 The gage on the left is called a compound gage because it reads below atmospheric pressure in inches Hg (mercury) and above atmospheric pressure in psig. The right-hand gage reads high pressure up to 500 psig. *Photo by Bill Johnson*

Figure 1–24. The gage on the left reads pressures above and below atmospheric pressure. It is called a *compound gage.* The gage on the right will read up to 500 psi and is called the *high-pressure (high-side) gage.*

SAFETY PRECAUTION: Working with temperatures that are above or below body temperature can cause skin and flesh damage. Proper protection, such as gloves and safety glasses, **must be used.** Pressures that are above or below the atmosphere's pressure can cause bodily injury. A vacuum can cause a blood blister on the skin. Pressure above atmospheric can pierce the skin or inflict damage when blowing air lifts small objects like filings.

These gages read 0 psi when opened to the atmosphere. If they do not, then they should be calibrated to 0 psi. These gages are designed to read pounds-per-square-inch gage pressure (psig). Atmospheric pressure is used as the starting or reference point. If you want to know what the absolute pressure is, you must add the atmospheric pressure to the gage reading. For example, to convert a gage reading of 50 psig to absolute pressure, you must add the atmospheric pressure of 14.696 psi to the gage reading. Let us round off 14.696 to 15 for this example. Then 50 psig + 15 = 65 psia (pounds per square inch absolute), **Figure 1–25.**

1.14 TEMPERATURE CONVERSION— FAHRENHEIT AND CELSIUS

You may find it necessary to convert specific temperatures from Fahrenheit to Celsius or from Celsius to Fahrenheit. This conversion can be done by using the Temperature Conversion Table in the appendix or by using a formula.

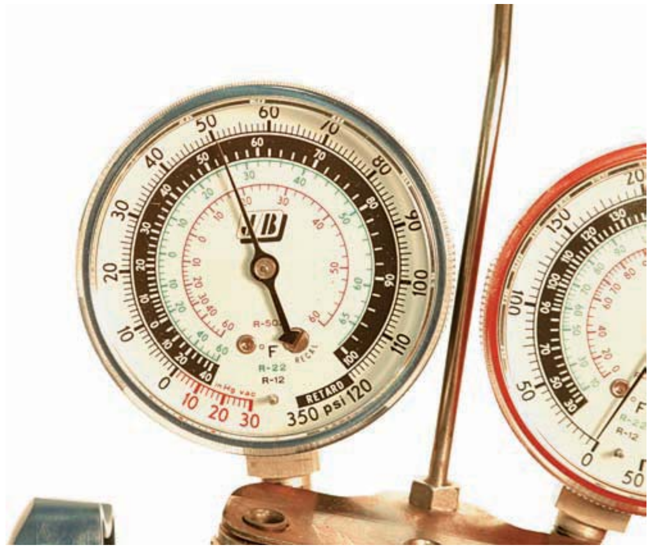


Figure 1–25 This gage reads 50 psig. To convert this gage reading to psia, add 50 psig to 15 psi (atmospheric pressure) for a sum of 65 psia. *Photo by Bill Johnson*

Using the table:

To convert a room temperature of 78°F to degrees Celsius, move down the column labeled Temperature to Be Converted until you find 78. Look to the right under the column marked °C, and you will find 25.6°C.

To convert 36°C to degrees Fahrenheit, look down the column labeled Temperature to Be Converted until you find 36. Look to the left and you will find 96.8°F.

Using formulas:

$$°C = \frac{°F - 32°}{1.8} \qquad °F = (1.8 \times °C) + 32°$$

or or

$$°C = \frac{5}{9}(°F - 32°) \quad °F = \left(\frac{9}{5} \times °C\right) + 32°$$

To convert a room temperature of 75°F to degrees C:

$$°C = \frac{75° - 32°}{1.8} = 23.9°$$

$$°C = 23.9°F$$

$$75°F = 23.9°C$$

To convert a room temperature of 25°C to degrees F:

$$°F = (1.8 \times 25°) + 32° = 77°$$

$$°F = 77°$$

$$25°C = 77°F$$

1.15 PRESSURE MEASURED IN METRIC TERMS

Pressure, like temperature, can be expressed in metric terms. Remember, pressure is an expression of force per unit of area. In the past, several terms have been used by different

countries to express the measurement of pressure, but the present standard metric expression for pressure is the term newton per square meter (N/m^2). Pressure in English measurement is expressed in pounds per square inch (psi). It is difficult to compare pounds per square inch and newton per square meter. To make this comparison easier, the newton per square meter has been given the name pascal in honor of the scientist and mathematician Blaise Pascal. The standard metric term for pressure is the kilopascal (kPa) or 1000 pascal. One psi is equal to 6890 pascal, or 6.89 kPa. To convert psi to kPa, simply multiply the number of psi by 6.89. Barometric pressure in metric terms is measured in mm Hg (millimeters of mercury). A standard atmosphere is 760 mm Hg or 101.3 kPa.

SUMMARY

- Thermometers measure temperature. Four temperature scales are Fahrenheit, Celsius, Fahrenheit absolute (Rankine), and Celsius absolute (Kelvin).
- Molecules in matter are constantly moving. The higher the temperature, the faster they move.
- The British thermal unit (Btu) describes the quantity of heat in a substance. One Btu is the amount of heat necessary to raise the temperature of 1 lb of water 1°F.
- The transfer of heat by conduction is the transfer of heat from molecule to molecule. As molecules in a substance move faster and with more energy, they cause others near them to do the same.
- The transfer of heat by convection is the actual moving of heat in a fluid (vapor state or liquid state) from one place to another.
- Radiant heat is a form of energy that does not depend on matter as a medium of transfer. Solid objects absorb the energy, become heated, and transfer the heat to the air.
- Sensible heat causes a rise in temperature of a substance.
- Latent (or hidden) heat is that heat added to a substance causing a change of state and not registering on a thermometer. For example, heat added to melting ice causes ice to melt but does not increase the temperature.
- Specific heat is the amount of heat (measured in Btu) required to raise the temperature of 1 lb of a substance 1°F. Substances have different specific heats.
- Pressure is the force applied to a specific unit of area. The atmosphere around the earth has weight and therefore exerts pressure.
- Barometers measure atmospheric pressures in inches of mercury. Two barometers used are the mercury and the aneroid.
- Gages have been developed to measure pressures in enclosed systems. Two common gages used in the air-conditioning, heating, and refrigeration industry are the compound gage and the high-pressure gage. The compound gage reads pressures both above and below atmospheric pressure.
- The metric term kilopascal (kPa) is used to express pressure in the refrigeration and air-conditioning field.

REVIEW QUESTIONS

1. Temperature is defined as
   A. how hot it is.
   B. the level of heat.
   C. how cold it is.
   D. why it is hot.
2. State the standard conditions for water to boil at 212°F.
3. List four types of temperature scales.
4. Under standard conditions, water freezes at _____°C.
5. Molecular motion stops at _____°F.
6. One British thermal unit will raise the temperature of _____ lb of water _____°F.
7. In which direction does heat flow?
   A. From a cold substance to a cold substance
   B. Up
   C. Down
   D. From a warm substance to a cold substance
8. Describe heat transfer by conduction.
9. A rise in sensible heat causes
   A. a rise in a thermometer.
   B. a fall in a thermometer.
   C. no change in a thermometer.
   D. ice to melt.
10. Latent heat causes
    A. a rise in a thermometer.
    B. temperature to rise.
    C. a change of state.
    D. temperature to fall.
11. Describe how heat is transferred by convection.
12. Describe how heat is transferred by radiation.
13. Specific heat is the amount of heat necessary to raise the temperature of 1 lb of a _____ 1°F.
14. Atmospheric pressure at sea level under standard conditions is _____ inches of mercury (Hg) or _____ pounds per square inch absolute (psia).
15. Describe the difference between a mercury and an aneroid barometer.
16. Pressure inside a Bourdon tube pressure gage causes the Bourdon tube to straighten or curl?
17. To change from psig to psia you must add _____ to psig.
18. Convert 80°F to Celsius.
19. Convert 22°C to Fahrenheit.
20. Convert 70 psig to kPa (kilopascal).

UNIT 2 Matter and Energy

OBJECTIVES

After studying this unit, you should be able to

- define matter.
- list the three states in which matter is commonly found.
- define density.
- discuss Boyle's Law.
- state Charles' Law.
- discuss Dalton's Law as it relates to the pressure of different gases.
- define specific gravity and specific volume.
- state two forms of energy important to the air-conditioning (heating and cooling) and refrigeration industry.
- describe work and state the formula used to determine the amount of work in a given task.
- define horsepower.
- convert horsepower to watts.
- convert watts to British thermal units.

2.1 MATTER

Matter is commonly explained as a substance that occupies space and has mass. The weight comes from the earth's gravitational pull. Matter is made up of atoms. Atoms are very small parts of a substance and may combine to form molecules. Atoms of one substance may be combined chemically with those of another to form a new substance. When molecules are formed they cannot be broken down any further without changing the chemical nature of the substance. Matter also exists in three states: *solids, liquids,* and *gases.* The heat content and pressure determine the state of matter. For instance, water is made up of molecules containing atoms of hydrogen and oxygen. Two atoms of hydrogen and one atom of oxygen are in each molecule of water. The chemical expression of these molecules is H_2O.

Water in the solid state is known as ice. It exerts all of its force downward—it has weight. The molecules of the water are highly attracted to each other, **Figure 2–1.**

When the water is heated above the freezing point, it begins to change to a liquid state. The molecular activity is higher, and the water molecules have less attraction for each other. Water in the liquid state exerts a pressure outward and downward. Because water pressure is proportional to its depth, water seeks a level surface where its pressure equals that of the atmosphere above it, **Figure 2–2.**

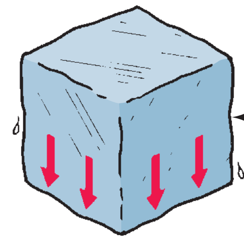


Figure 2–1 Solids exert all their pressure downward. The molecules of solid water have a great attraction for each other and hold together.

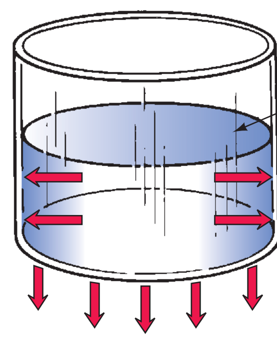


Figure 2–2 The water in the container exerts pressure outward and downward. The outward pressure is what makes water seek its own level. The water molecules still have a small amount of adhesion to each other. The pressure is proportional to the depth.

Water heated above the liquid state, 212°F at standard conditions, becomes a vapor. In the vapor state the molecules have even less attraction for each other and are said to travel at random. The vapor exerts pressure more or less in all directions, **Figure 2–3.**

The study of matter leads to the study of other terms that help to understand how different substances compare with each other.

2.2 MASS AND WEIGHT

Mass is the property of matter that responds to gravitational attraction. *Weight* is the force that matter (solid, liquid, or gas) applies to a supporting surface when it is at rest.

Weight is not a property of matter but is dependent on the gravitational attraction. The stronger the force of gravity, the more an object will weigh. The earth has stronger gravitational attraction forces than the moon. This is why objects weigh more on the earth than on the moon.

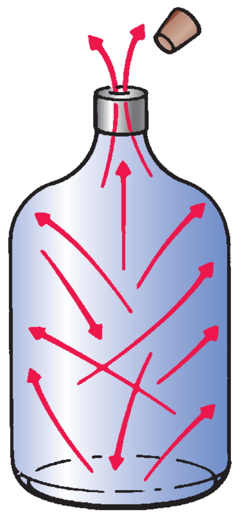


Figure 2–3 Gas molecules travel at random. When a container with a small amount of gas pressure is opened, the gas molecules seem to repel each other and fly out.

All solid matter has mass. A liquid such as water is said to have mass. The air in the atmosphere has weight and mass. When the atmosphere is evacuated out of a jar, the mass is removed, and a vacuum is created.

2.3 DENSITY

The *density* of a substance describes its mass-to-volume relationship. The mass contained in a particular volume is the density of that substance. In the British system of units, volume is measured in cubic feet. Sometimes it is advantageous to compare different substances according to weight per unit volume. Water, for example, has a density of 62.4 lb/ft^3. Wood floats on water because the density (weight per volume) of wood is less than the density of water. In other words, it weighs less per cubic foot. Iron, on the other hand, sinks because it is denser than water. **Figure 2–4** lists some typical densities.

2.4 SPECIFIC GRAVITY

Specific gravity is a unitless number because it is the density of a substance divided by the density of water. Water is simply used as the standard comparison. The density of water is 62.4 lb/ft^3. So, the specific gravity of water is 62.4 lb/ft^3 ÷ 62.4 lb/ft^3 = 1. Notice that the units cancel because of the division. The density of red brass is 548 lb/ft^3. Its specific gravity is then 548 lb/ft^3 ÷ 62.4 lb/ft^3 = 8.78. **Figure 2–4** lists some typical specific gravities of substances.

SUBSTANCE	DENSITY lb/ft^3	SPECIFIC GRAVITY
ALUMINUM	171	2.74
BRASS (RED)	548	8.78
COPPER	556	8.91
GOLD	1208	19.36
ICE @ 32°F	57.5	0.92
TUNGSTEN	1210	19.39
WATER	62.4	1
MARBLE	162	2.596

Figure 2–4 Table of density and specific gravity.

2.5 SPECIFIC VOLUME

Specific volume compares the volume that each pound of gas occupies. It specifies that there must be only 1 lb of the gas. Its units are ft^3/lb. This differs from total volume whose units are simply ft^3. One pound of clean dry air has a total volume of 13.33 ft^3 at standard atmospheric conditions. Its specific volume would then be 13.33 ft^3/lb. Hydrogen has a specific volume of 179 ft^3/lb under the same conditions. Because more cubic feet of hydrogen exist per pound, it has a higher specific volume, thus is lighter than air. Although both are gases, the hydrogen has a tendency to rise when mixed with air.

Specific volume and density are considered inverses of one another. This means that specific volume = 1 ÷ density and that density = 1 ÷ specific volume. If one knows the specific volume of a substance, its density can be calculated and vice versa. For example, the specific volume of dry air is 13.33 ft^3/lb. Its density would then be 1 ÷ 13.33 ft^3/lb = .075 lb/ft^3. Notice that even the units are inverse to one another. Substances with high specific volumes can be said to have low densities. Also, substances with high densities can be said to have low specific volumes.

The specific volume of air is a factor in determining the fan horsepower needed in air-conditioning work. As an example, a low specific volume of air requires a higher horsepower blower motor, and a high specific volume of air requires a lower horsepower blower motor.

Natural gas is explosive when mixed with air, but it is lighter than air and has a tendency to rise like hydrogen. Propane gas is another frequently used heating gas and has to be treated differently from natural gas because it is heavier than air. Propane has a tendency to fall and collect in low places and to cause potential danger from ignition.

The specific volumes of various gases that are pumped is valuable information that enables the engineer to choose the size of the compressor or vapor pump to do a particular job. The specific volumes for vapors vary according to the pressure the vapor is under. An example is refrigerant-22, which is a common refrigerant used in residential air-conditioning units. At 3 psig about 2.5 ft^3 of gas must be pumped to move 1 lb of gas. At the standard design condition of 70 psig, only 0.48 ft^3 of gas needs to be pumped to move 1 lb of the same gas. A complete breakdown of specific volume can be found in the properties of saturated and superheated conditions for liquid and/or vapor in engineering manuals for any refrigerant.

2.6 GAS LAWS

It is necessary to have a working knowledge of gases and how they respond to pressure and temperature changes. Several scientists made significant discoveries many years ago.

A simple explanation of some of the gas laws developed by these scientists may help you understand the reaction of gases and the pressure/temperature/volume relationships in various parts of a refrigeration system. Whenever using pressure or temperature in an equation like the gas laws, one has to use the absolute scales of pressure (psia) and temperature (Rankine or Kelvin), or the solutions to these equations will be meaningless. Absolute scales use zero as their starting points, because zero is where molecular motion actually begins.

Boyle's Law

Robert Boyle, a citizen of Ireland, developed in the early 1600s what has come to be known as Boyle's Law. He discovered that when pressure is applied to a volume of air that is contained, the volume of air becomes smaller and the pressure greater. Boyle's Law states that *the volume of a gas varies inversely with the absolute pressure, provided the temperature remains constant.* For example, if a cylinder with a piston at the bottom and enclosed at the top were filled with air and the piston moved halfway up the cylinder, the pressure of the air would double, **Figure 2–5.** That part of the law pertaining to the temperature remaining constant keeps Boyle's Law from being used in practical situations. This is because when a gas is compressed some heat is transferred to the gas from the mechanical compression, and when gas is expanded heat is given up. However, this law, when combined with another, will make it practical to use.

The formula for Boyle's Law is as follows:

$$P_1 \times V_1 = P_2 \times V_2$$

where P_1 = original absolute pressure
V_1 = original volume
P_2 = new pressure
V_2 = new volume

For example, if the original pressure was 40 psia and the original volume 30 in^3, what would the new volume be if the pressure were increased to 50 psia? We are determining the new volume. The formula would have to be rearranged so we could find the new volume.

$$V_2 = \frac{P_1 \times V_1}{P_2}$$

$$V_2 = \frac{40 \times 30}{50}$$

$$V_2 = 24 \text{ in}^3$$

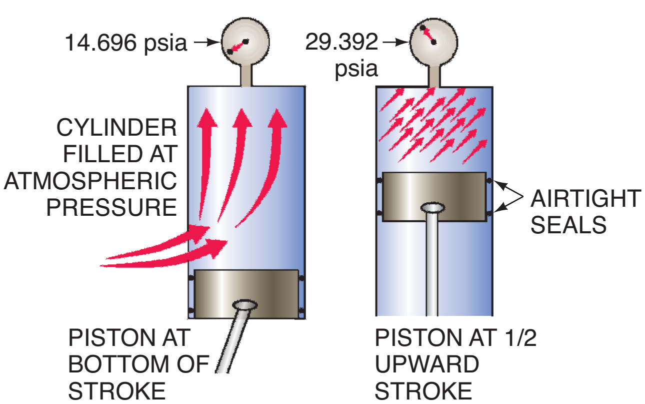


Figure 2–5 Absolute pressure in a cylinder doubles when the volume is reduced by half.

Charles' Law

In the 1800s, a French scientist named Jacques Charles made discoveries regarding the effect of temperature on gases. Charles' Law states that *at a constant pressure, the volume of a gas varies directly as to the absolute temperature, and at a constant volume, the pressure of a gas varies directly with the absolute temperature.* Stated in a different form, when a gas is heated and if it is free to expand, it will do so, and the volume will vary directly as to the absolute temperature. If a gas is confined in a container that will not expand and it is heated, the pressure will vary directly with the absolute temperature.

This law can also be stated with formulas. Two formulas are needed because one part of the law pertains to pressure and temperature and the other part to volume and temperature.

This formula pertains to volume and temperature:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

where V_1 = original volume
V_2 = new volume
T_1 = original temperature
T_2 = new temperature

If 2000 ft^3 of air is passed through a gas furnace and heated from 75°F room temperature to 130°F, what is the volume of the air leaving the heating unit? See **Figure 2–6.**

V_1 = 2000 ft^3
T_1 = 75°F + 460° = 535°R (absolute)
V_2 = unknown
T_2 = 130°F + 460° = 590°R

We must mathematically rearrange the formula so that the unknown is alone on one side of the equation.

$$V_2 = \frac{V_1 \times T_2}{T_1}$$

$$V_2 = \frac{2000 \text{ ft}^3 \times 590°\text{R}}{535°\text{R}}$$

$$V_2 = 2205.6 \text{ ft}^3$$

The air expanded when heated.

The following formula pertains to pressure and temperature:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

where P_1 = original pressure
T_1 = original temperature
P_2 = new pressure
T_2 = new temperature

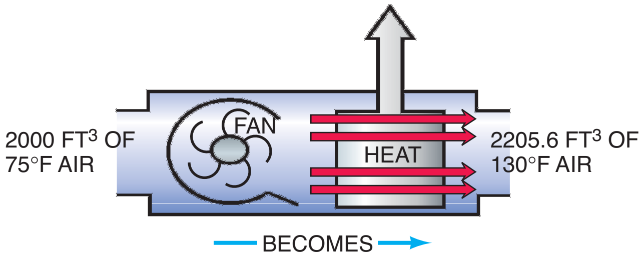


Figure 2–6 Air expands when heated.

If a large natural gas tank holding 500,000 ft^3 of gas is stored at 70°F in the spring and the temperature rises to 95°F in the summer, what would the pressure be if the original pressure was 25 psig in the spring?

P_1 = 25 psig + 14.696 (atmospheric pressure) or 39.696 psia
T_1 = 70°F + 460°R or 530°R (absolute)
P_2 = unknown
T_2 = 95°F + 460° or 555°R (absolute)

Again the formula must be rearranged so that the unknown is on one side of the equation by itself.

$$P_2 = \frac{P_1 \times T_2}{T_1}$$

$$P_2 = \frac{39.696 \text{ psia} \times 555°\text{R}}{530°\text{R}}$$

$$P_2 = 41.57 \text{ psia} - 14.696 = 26.87 \text{ psig}$$

General Law of Perfect Gas

A general gas law, often called the General Law of Perfect Gas, is a combination of Boyle's and Charles' Laws. This combination law is more practical because it includes temperature, pressure, and volume.

The formula for this law can be stated as follows:

$$\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2}$$

where P_1 = original pressure
V_1 = original volume
T_1 = original temperature
P_2 = new pressure
V_2 = new volume
T_2 = new temperature

For example, 20 ft^3 of gas is being stored in a container at 100°F and a pressure of 50 psig. This container is connected by pipe to one that will hold 30 ft^3 (a total of 50 ft^3), and the gas is allowed to equalize between the two containers. The temperature of the gas is lowered to 80°F. What is the pressure in the combined containers?

P_1 = 50 psig + 14.696 or 64.696
V_1 = 20 ft^3
T_1 = 100° + 460°R = 560°R
P_2 = unknown
V_2 = 50 ft^3
T_2 = 80°F + 460° or 540°R

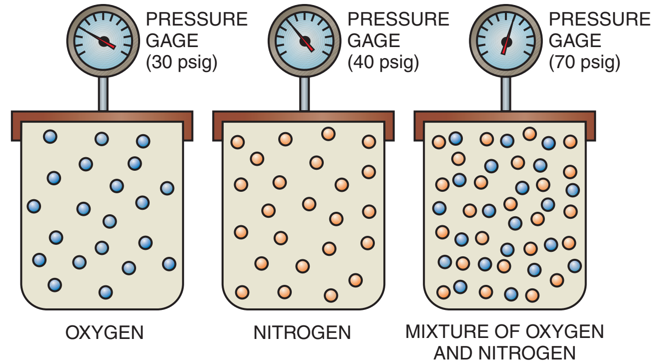


Figure 2–7 Dalton's Law of Partial Pressures. The total pressure is the sum of the individual pressures of each gas.

The formula is mathematically rearranged to solve for the unknown P_2:

$$P_2 = \frac{P_1 \times V_1 \times T_2}{T_1 \times V_2}$$

$$P_2 = \frac{64.696 \times 20 \times 540}{560 \times 50}$$

$$P_2 = 24.95 \text{ psia} - 14.696 = 10.26 \text{ psig}$$

Dalton's Law

In the early 1800s, John Dalton, an English mathematics professor, made the discovery that the atmosphere is made up of several different gases. He found that each gas created its own pressure and that the total pressure was the sum of each. Dalton's Law states that *the total pressure of a confined mixture of gases is the sum of the pressures of each of the gases in the mixture.* For example, when nitrogen and oxygen are placed in a closed container, the pressure on the container will be the total pressure of the nitrogen as if it were in the container by itself added to the oxygen pressure in the container by itself, **Figure 2–7.**

2.7 ENERGY

Using energy properly to operate equipment is a major goal of the air-conditioning and refrigeration industry. Energy in the form of electricity drives the motors; heat energy from the fossil fuels of natural gas, oil, and coal heats homes and industry. What is this energy and how is it used?

The only new energy we get is from the sun heating the earth. Most of the energy we use is converted to usable heat from something already here (e.g., fossil fuels). This conversion from fuel to heat can be direct or indirect. An example of direct conversion is a gas furnace, which converts the gas flame to usable heat by combustion. The gas is burned in a combustion chamber, and heat from combustion is transferred to circulated air by conduction through the heat exchanger wall of thin steel. Some gas furnaces may have a condensing heat exchanger. This will be explained in the unit on gas heat. The heated air is then distributed throughout the heated space, **Figure 2–8.**

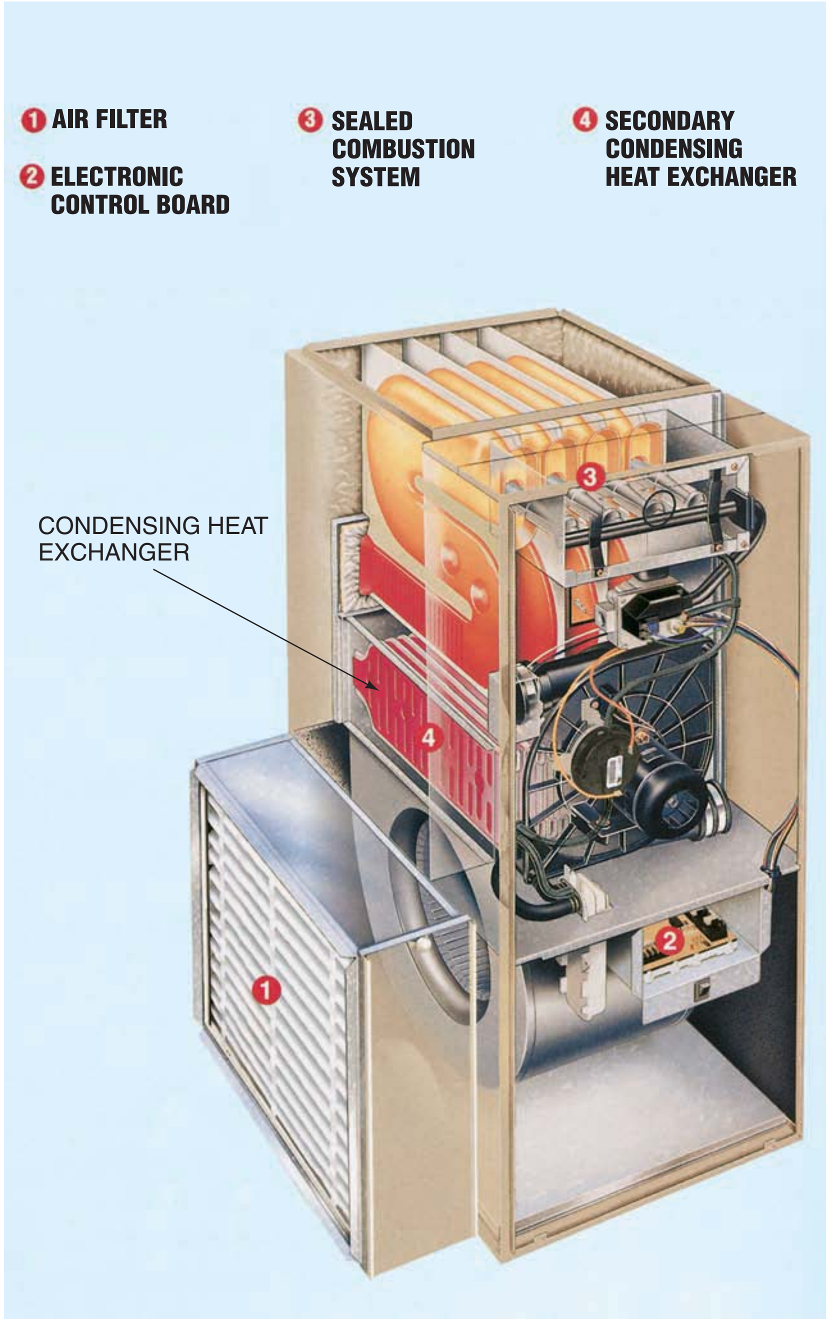


Figure 2–8 A high-efficiency furnace with burners on top of the heat exchanger. *Courtesy Bryant Heating and Cooling Systems*

An example of indirect conversion is a fossil-fuel power plant. Gas may be used in the power plant to produce the steam that turns a steam turbine generator to produce electricity. The electricity is then distributed by the local power company and consumed locally as electric heat, **Figure 2–9.**

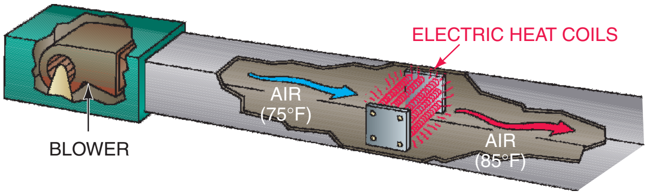


Figure 2–9 An electric heat airstream.

2.8 CONSERVATION OF ENERGY

The preceding leads to the law of conservation of energy. This law states that *energy is neither created nor destroyed but can be converted from one form to another.* It can then be said that energy can be accounted for.

Most of the energy we use is a result of the sun supporting plant growth for thousands of years. Fossil fuels come from decayed vegetable and animal matter covered by earth and rock during changes in the earth's surface. This decayed matter is in various states, such as gas, oil, or coal, depending on the conditions it was subjected to in the past, **Figure 2–10.** The energy stored in fossil fuels is called chemical energy because a chemical reaction is needed to release the energy.

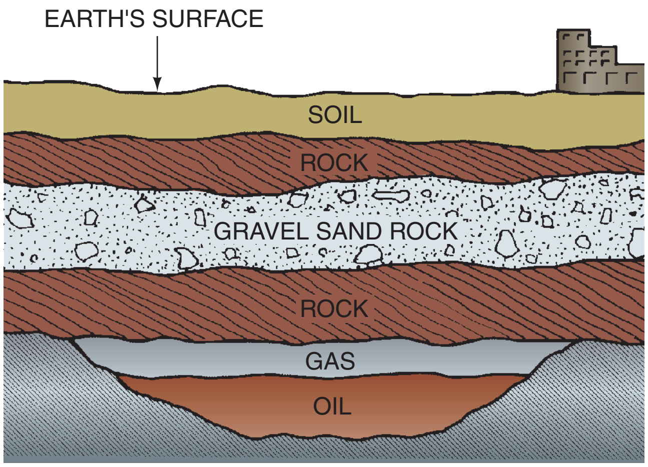


Figure 2–10 Gas and oil deposits settle into depressions.

2.9 ENERGY CONTAINED IN HEAT

Temperature is a measure of the degree of heat or the heat intensity, but not necessarily the amount of heat. Heat is a form of energy because of the motion of molecules. To be specific, heat is thermal energy. If two substances of different temperatures are moved close to each other, heat from the substance with the higher temperature will flow to the one with the lower temperature, **Figure 2–11(A).** Because molecular motion does not stop until −460°F, energy is still available in a substance even at very low temperatures. This energy is in relationship to other substances that are at lower temperatures. For example, if two substances at very low temperatures are moved close together, heat will transfer from the warmer substance to the colder one. In **Figure 2–11(B)** a substance at −200°F is placed next to a substance at −350°F. As we discussed earlier, the warmer substance gives up heat (energy) to the cooler substance. The energy used by home and industry is not at these low levels.

Most of the heat energy used in homes and industry is provided from fossil fuels, but some comes from electrical energy. As shown in **Figure 2–9,** electron flow in high-resistance wire causes the wire to become hot, thus heating the air. A moving airstream is then passed over the heated wire, allowing heat to be transferred to the air by conduction and moved to the heated space by forced convection (the fan).

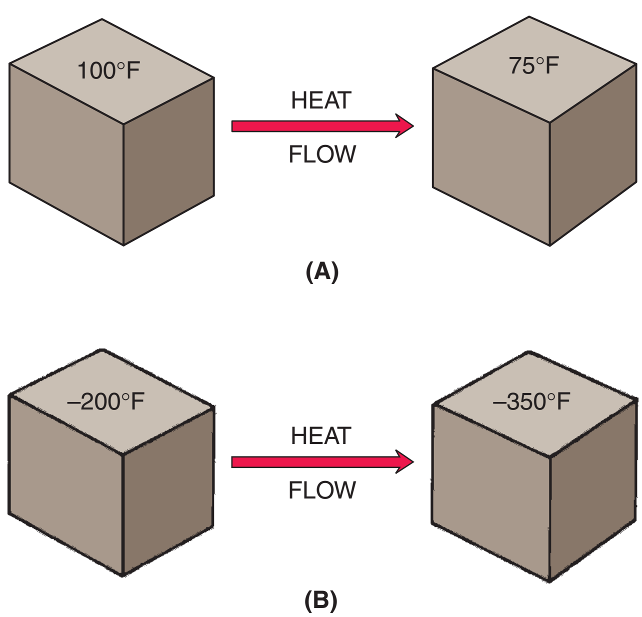


Figure 2–11 **(A)** If two substances of different temperatures are moved close to each other, heat from the substance with the higher temperature will flow to the one with the lower temperature. **(B)** Heat energy is still available at these low temperatures and will transfer from the warmer substance to the colder substance.

2.10 ENERGY IN MAGNETISM

Magnetism is another method of converting electron flow to usable energy. Electron flow is used to develop magnetism to turn motors. The motors turn the prime movers—fans, pumps, compressors—of air, water, and refrigerant. In **Figure 2–12** an electric motor turns a water pump to boost the water pressure from 20 to 60 psig. This takes energy. The energy in this example is purchased from the power company.

The preceding examples serve only as an introduction to the concepts of chemical energy, heat energy, and electrical energy. Each subject will later be covered in detail. For now it is important to realize that any system furnishing heating or cooling uses energy.

2.11 PURCHASE OF ENERGY

Energy must be transferred from one owner to another and accounted for. This energy is purchased as a fossil fuel or as electric power. Energy purchased as a fossil fuel is normally purchased by the unit. Natural gas is an example. Natural gas flows through a meter that measures how many cubic feet have passed during some time span, such as a month. Fuel oil is normally sold by the gallon, coal by the ton. Electrical energy is sold by the kilowatt-hour or kWh. The amount of heat each of these units contains is known, so a known amount of heat is purchased. Natural gas, for instance, has a heat content of about 1000 Btu/ft^3; whereas the heat content of coal varies from one type of coal to another.

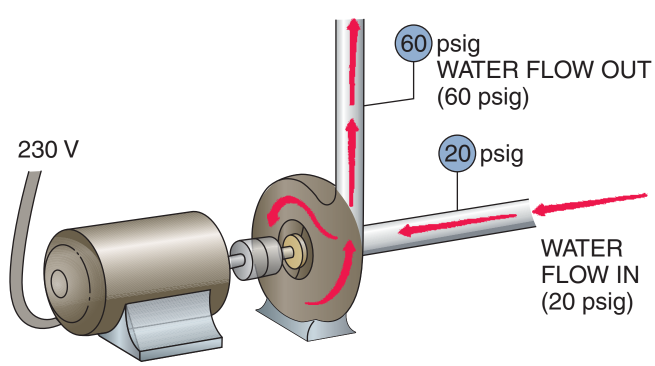


Figure 2–12 Electrical energy used in an electric motor is converted to work to boost water pressure to force circulation.

2.12 ENERGY USED AS WORK

Energy purchased from electrical utilities is known as electric power. *Power* is the rate of doing work. *Work* can be explained as a force moving an object in the direction of the force. It is expressed by this formula:

$$\text{Work} = \text{Force} \times \text{Distance}$$

For instance, when a 150-lb man climbs a flight of stairs 100 ft high (about the height of a 10-story building), he performs work. But how much? The amount of work in this example is equivalent to the amount of work necessary to lift this man the same height. We can calculate the work by using the preceding formula.

$$\begin{aligned}\text{Work} &= 150 \text{ lb} \times 100 \text{ ft}\\ &= 15{,}000 \text{ ft-lb}\end{aligned}$$

Notice that no time limit has been added. This example can be accomplished by a healthy man in a few minutes. But if the task were to be accomplished by a machine such as an elevator, more information is necessary. Do we want to take seconds, minutes, or hours to do the job? The faster the job is accomplished, the more power is required.

2.13 POWER

Power is the rate of doing work. An expression of power is *horsepower (hp).* Many years ago it was determined that an average good horse could lift the equivalent of 33,000 lb to a height of 1 ft in 1 min, which is the same as 33,000 ft-lb/min or 1 hp. This describes a rate of doing work because time has been added. Keep in mind that lifting 330 lb to a height of 100 ft in 1 min or lifting 660 lb 50 ft in 1 min is the same amount of work. As a point of reference, the fan motor in the average furnace can be rated at 1/2 hp. See **Figure 2–13** for an illustration of the horse lifting 1 hp.

When the horsepower is compared with the man climbing the stairs, the man would have to climb the 100 ft in less than 30 sec to equal 1 hp. That makes the task seem even harder. A 1/2-hp motor could lift the man 100 ft in 1 min if only the man were lifted. The reason is that 15,000 ft-lb of work is required. (Remember that 33,000 ft-lb of work in 1 min equals 1 hp.)

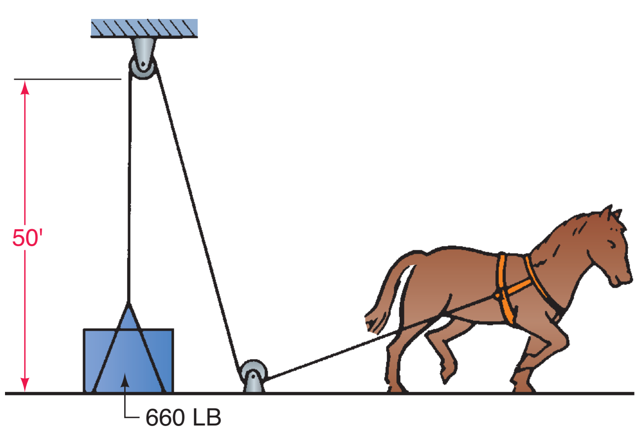


Figure 2–13 When a horse can lift 660 lb to a height of 50 ft in 1 min, it has done the equivalent of 33,000 ft-lb of work in 1 min, or 1 hp.

Our purpose in discussing these topics is to help you understand how to use power effectively and to understand how power companies determine their methods of charging for power.

2.14 ELECTRICAL POWER—THE WATT

The unit of measurement for electrical power is the *watt (W).* This is the unit used by the power company. When converted to electrical energy, 1 hp = 746 W; that is, when 746 W of electrical power is properly used, the equivalent of 1 hp of work has been accomplished.

Fossil-fuel energy can be compared with electrical energy, and one form of energy can be converted to the other. There must be some basis, however, for conversion so that one fuel can be compared with another. The examples we use to illustrate this comparison will not take efficiencies into account. Efficiencies for the various fuels will be covered in the section on applications for each fuel. Some examples of conversions follow.

1. **Converting electric heat rated in kilowatts (kW) to the equivalent gas or oil heat rated in Btu.** Suppose that we want to know the capacity in Btu for a 20-kW electric heater (a kilowatt is 1000 watts). 1 kW = 3413 Btu.

$$20 \text{ kW} \times 3413 \text{ Btu/kW} = 68{,}260 \text{ Btu of heat energy}$$

2. **Converting Btu to kW.** Suppose that a gas or oil furnace has an output capacity of 100,000 Btu/h. Since 3413 Btu = 1 kW, we have

$$100{,}000 \text{ Btu} \div 3413 \text{ Btu/kW} = 29.3 \text{ kW}$$

In other words, a 29.3-kW electric heat system would be required to replace the 100,000-Btu/h furnace.

Contact the local utility company for rate comparisons between different fuels. SAFETY PRECAUTION: Any device that consumes power, such as an electric motor or gas furnace, is potentially dangerous. These devices should only be handled or adjusted by experienced people.

SUMMARY

- Matter takes up space, has mass, and can be in the form of a solid, a liquid, or a gas.
- The weight of a substance at rest on the earth is proportional to its mass.
- In the British system of units, density is the weight of a substance per cubic foot.
- Specific gravity is the term used to compare the density of various substances.
- Specific volume is the amount of space a pound of a vapor or a gas will occupy.
- Boyle's Law states that the volume of a gas varies inversely with the absolute pressure, provided the temperature remains constant.

- Charles' Law states that at a constant pressure, the volume of a gas varies directly as to the absolute temperature, and at a constant volume the pressure of a gas varies directly with the absolute temperature.
- Dalton's Law states that the total pressure of a confined mixture of gases is the sum of the pressures of each of the gases in the mixture.
- Electrical energy and heat energy are two forms of energy used in this industry.
- Fossil fuels are purchased by the unit. Natural gas is metered by the cubic foot; oil is purchased by the gallon; and coal is purchased by the ton. Electricity is purchased from the electric utility company by the kilowatt-hour (kWh).
- Work is the amount of force necessary to move an object: Work = Force × Distance.
- Horsepower is the equivalent of lifting 33,000 lb to a height of 1 ft in 1 min or some combination totaling the same.
- Watts are a measurement of electrical power. One horsepower equals 746 W.
- 3.413 Btu = 1 W. 1 kW (1000 W) = 3413 Btu.

REVIEW QUESTIONS

1. Matter is a substance that occupies space and has
   A. color.
   B. texture.
   C. temperature.
   D. mass.

2. What are the three states in which matter is commonly found?

3. _________ is the term used for water when it is in the solid state.

4. In what direction does a solid exert force?

5. In what direction does a liquid exert force?

6. Vapor exerts pressure in what direction?
   A. Outward
   B. Upward
   C. Downward
   D. All of the above

7. Define density.

8. Define specific gravity.

9. Describe specific volume.

10. Why does an object weigh less on the moon than on the earth?

11. The density of tungsten is 1210 lb/ft^3. What would be its specific volume?

12. The specific volume of red brass is .001865 ft^3/lb. What would be its density?

13. Aluminum has a density of 171 lb/ft^3. What would be its specific gravity?

14. Four pounds of a gas occupies 10 ft^3. What would be its total volume, density, and specific gravity?

15. Why is information regarding the specific volume of gases important to the designer of air-conditioning, heating, and refrigeration equipment?

16. Whose law states that the volume of a gas varies inversely with the absolute pressure, as long as the temperature remains constant?
   A. Charles'
   B. Boyle's
   C. Newton's
   D. Dalton's

17. At a constant pressure how does a volume of gas vary with respect to the absolute temperature?

18. Describe Dalton's Law as it relates to a confined mixture of gases.

19. What are the two types of energy most frequently used or considered in this industry?

20. How were fossil fuels formed?

21. _________ is the time rate of doing work.

22. State the formula for determining the amount of work accomplished in a particular task.

23. If an air-conditioning compressor weighing 300 lb had to be lifted 4 ft to be mounted on a base, how many ft-lb of work must be accomplished?

24. Describe horsepower and list the three quantities needed to determine horsepower.

25. How many watts of electrical energy are equal to 1 hp?

26. How many Btu of heat can be produced by 4 kWh of electricity?

27. How many Btu/h would be produced in a 12-kW electric heater?

28. What unit of energy does the power company charge the consumer for?

29. If a 30-ft^3 volume of air at 10 psig is compressed to 25 ft^3 at a constant temperature, what would be the new pressure in psig?

30. If 3000 ft^3 of air is crossing an evaporator coil and is cooled from 75°F to 55°F, what would be the volume of air in ft^3 exiting the evaporator coil?

31. A gas is compressed inside a compressor's cylinder. When the piston is at its bottom dead center, the gas is initially at 10 psig, 65°F, and 10.5 in^3. After compression and when the piston is at top dead center, the gas is 180°F and occupies 1.5 in^3. What would be the new pressure of the gas in psig?

UNIT 3 Refrigeration and Refrigerants

OBJECTIVES

After studying this unit, you should be able to

- discuss applications for high-, medium-, and low-temperature refrigeration.
- describe the term *ton of refrigeration.*
- describe the basic refrigeration cycle.
- explain the relationship between pressure and the boiling point of water or other liquids.
- describe the function of the evaporator or cooling coil.
- explain the purpose of the compressor.
- list the compressors normally used in residential and light commercial buildings.
- discuss the function of the condensing coil.
- state the purpose of the metering device.
- list four characteristics to consider when choosing a refrigerant for a system.
- list the designated colors for refrigerant cylinders for various types of refrigerants.
- describe how refrigerants can be stored or processed while refrigeration systems are being serviced.
- plot a refrigeration cycle for refrigerants (R-22, R-12, R-134a, and R-502) on a pressure/enthalpy diagram.
- plot a refrigeration cycle on a pressure/enthalpy diagram for refrigerant blends R-404A and R-410A.
- plot a refrigeration cycle on a pressure/enthalpy diagram for a refrigerant blend (R-407C) that has a noticeable temperature glide.

SAFETY CHECKLIST

✔ Areas in which there is the potential for refrigerant leaks should be properly ventilated.

✔ Extra precautions should be taken to ensure that no refrigerant leaks occur near an open flame.

✔ Refrigerants are stored in pressurized containers and should be handled with care. Goggles with side shields and gloves should be worn when checking pressures and when transferring refrigerants from the container to a system or from the system to an approved container.

3.1 INTRODUCTION TO REFRIGERATION

This unit is an introduction to refrigeration and refrigerants. The term refrigeration is used here to include both the cooling process for preserving food and comfort cooling (air conditioning).

Preserving food is one of the most valuable uses of refrigeration. The rate of food spoilage gets slower as molecular motion slows. This retards the growth of bacteria that causes food to spoil. Below the frozen hard point, food-spoiling bacteria stop growing. The frozen hard point for most foods is considered to be 0°F. The food temperature range between 35°F and 45°F is known in the industry as medium temperature; below 0°F is considered low temperature. These ranges are used to describe many types of refrigeration equipment and applications. Refrigeration systems that operate to produce warmer temperatures are referred to as high-temperature refrigeration systems. Comfort cooling systems, commonly referred to as air-conditioning systems, are used, for example, to cool our homes and commercial spaces and are classified as high-temperature refrigeration systems.

For many years dairy products and other perishables were stored in the coldest room in the house, the basement, the well, or a spring. In the South, temperatures as low as 55°F could be reached in the summer with underground water. This would add to the time that some foods could be kept. Ice in the North and to some extent in the South was placed in "ice boxes" in kitchens. The ice melted when it absorbed heat from the food in the box, cooling the food, **Figure 3–1.**

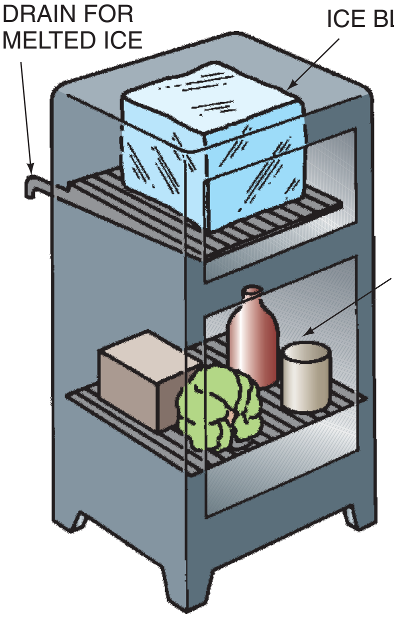


Figure 3–1 Ice boxes were made of wood at first, then metal. The boxes were insulated with cork. If a cooling unit were placed where the ice is, this would be a refrigerator.

In the early 1900s, ice was manufactured by mechanical refrigeration and sold to people with ice boxes, but still only the wealthy could afford it.

Also in the early 1900s, some companies manufactured the household refrigerator. Like all new items, it took a while to become popular. Now, most houses have a refrigerator with a freezing compartment. Modern refrigerators have become state-of-the-art appliances—and some models even include automatic beverage and ice dispensers, built-in television screens, and connections to the World Wide Web.

Frozen food was just beginning to become popular about the time World War II began. Because most people did not have a freezer at this time, central frozen food locker plants were established so that a family could have its own locker. Food that is frozen fresh is appealing because it stays fresh for a longer period of time. Refrigerated and frozen foods are so common now that most people take them for granted.

3.2 REFRIGERATION

Refrigeration **is the process of removing heat from a place where it is not wanted and transferring that heat to a place where it makes little or no difference.** In the average household, the room temperature from summer to winter is normally between 70°F and 90°F. The temperature inside the refrigerator fresh food section should be about 35°F. Heat flows naturally from a warm level to a cold level. Therefore, heat in the room is trying to flow into the refrigerator, and it does through the insulated walls, the door when it is opened, and warm food placed in the refrigerator, **Figure 3–2, Figure 3–3,** and **Figure 3–4.** For this reason, to increase the efficiency of the unit, it is always best to allow food to cool down to room temperature before placing it in the refrigerator.

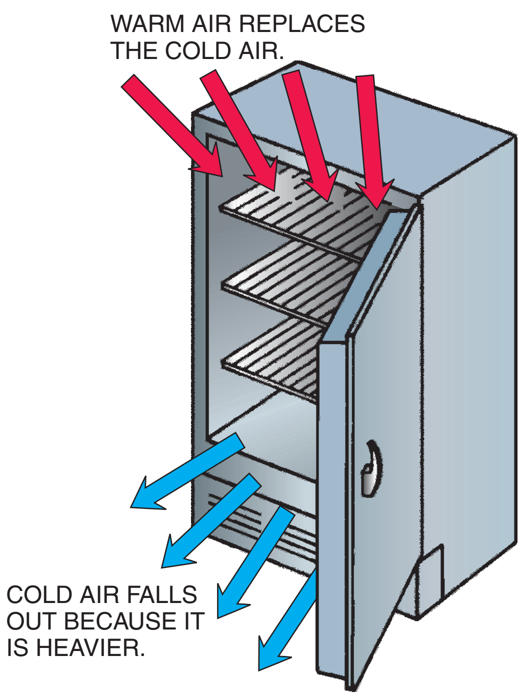


Figure 3–2 The colder air falls out of the refrigerator because it is heavier than the warmer air located outside the refrigerator. The cooler air is replaced with warmer air at the top. This is referred to as heat leakage.

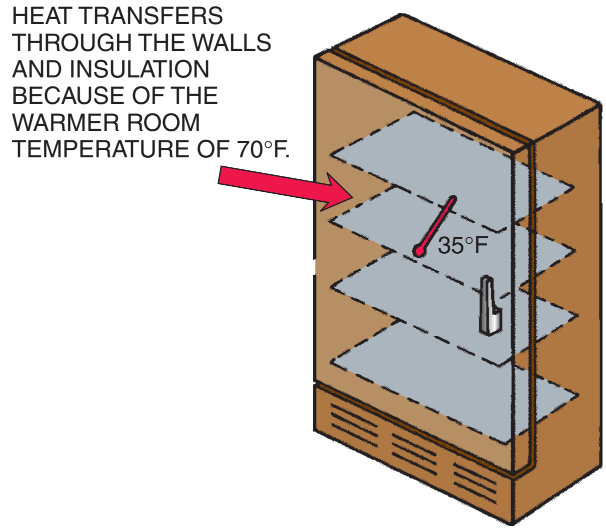


Figure 3–3 Heat transfers through the walls into the box by conduction. The walls have insulation, but this does not stop the heat leakage completely.

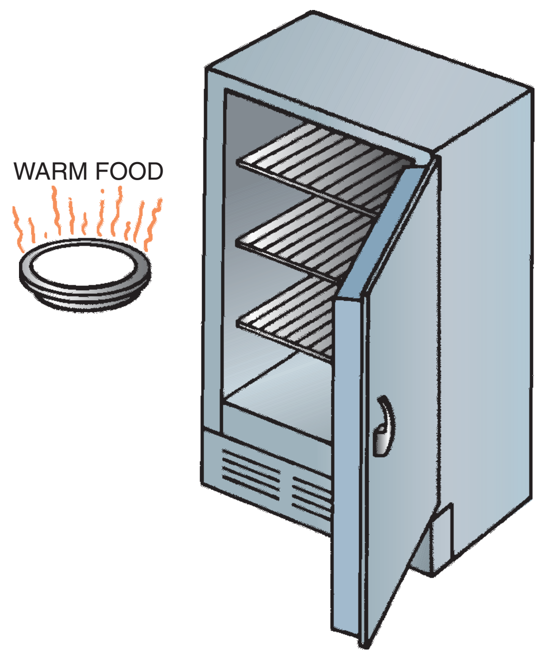


Figure 3–4 Warm food that is placed in the refrigerator adds heat to the refrigerator and is also considered heat leakage. This added heat has to be removed or the temperature inside the refrigerator will rise.

3.3 RATING REFRIGERATION EQUIPMENT

Refrigeration equipment must also have a capacity rating system so that equipment of different manufacturers and models can be compared. The method for rating refrigeration

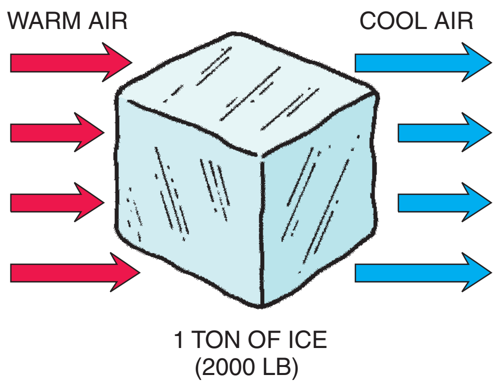


Figure 3–5 Ice requires 144 Btu/lb to melt. Melting 1 ton of ice requires 288,000 Btu (2000 lb × 144 Btu/lb = 288,000 Btu).

equipment capacity goes back to the days of using ice as the source for removing heat. It takes 144 Btu of heat energy to melt 1 lb of ice at 32°F. This same figure is also used in the capacity rating of refrigeration equipment.

The term for this capacity rating is the ton. *One ton of refrigeration* is the amount of heat required to melt 1 ton of ice in a 24-hour period. Previously, we saw that it takes 144 Btu of heat to melt 1 lb of ice. It would then take 2000 times that much heat to melt a ton of ice (2000 lb = 1 ton):

$$144 \text{ Btu/lb} \times 2000 \text{ lb} = 288{,}000 \text{ Btu}$$

When accomplished in a 24-hour period, it is known as 1 ton of refrigeration. The same rules apply when removing heat from a substance. For example, an air conditioner that has a 1-ton capacity will remove 288,000 Btu/24 h or 12,000 Btu/h (288,000 ÷ 24 = 12,000) or 200 Btu/min (12,000 ÷ 60 = 200), **Figure 3–5.**

3.4 THE REFRIGERATION PROCESS

The refrigerator has to pump the heat up the temperature scale from the 35°F or 0°F refrigeration compartments to the 70°F room. The components of the refrigerator are used to accomplish this task, **Figure 3–6.** The heat leaking into the refrigerator raises the air temperature but does not normally raise the temperature of the food an appreciable amount. If it did, the food would spoil. When the temperature inside the refrigerator rises to a predetermined level, the refrigeration system comes on and pumps the heat out.

The process of pumping heat out of the refrigerator could be compared to pumping water from a valley to the top of a hill. It takes just as much energy to pump water up the hill as it does to carry it. A water pump with a motor accomplishes work. If a gasoline engine, for instance, were driving the pump, the gasoline would be burned and converted to work energy. An electric motor uses electric power as work energy, **Figure 3–7.** Refrigeration is the process of moving heat from an area of lower temperature into an area or medium with higher temperature. This takes energy that must be purchased.

Following is an example using a residential window air-conditioning system to explain the basics of refrigeration. Residential air conditioning, whether a window unit or a central system, is considered to be high-temperature refrigeration and is used for comfort cooling. The residential system can be seen from the outside, touched, and listened to for examples that will be given.

The refrigeration concepts utilized in the residential air conditioner are the same as those in the household refrigerator. It pumps the heat from inside the house to the outside of the house, and the household refrigerator pumps heat from the refrigerator into the kitchen. In addition, heat leaks into the house just as heat leaks into the refrigerated compartments in the refrigerator.

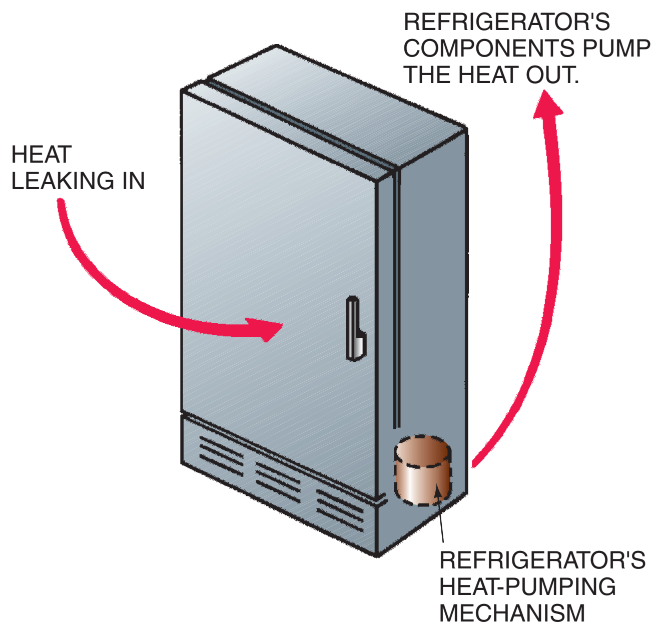


Figure 3–6 Heat that leaks into the refrigerator from any source must be removed by the refrigerator's heat-pumping mechanism. The heat has to be pumped from the cool, 35°F interior of the refrigerator to the warmer, 70°F air in the room in which the refrigerator is located.

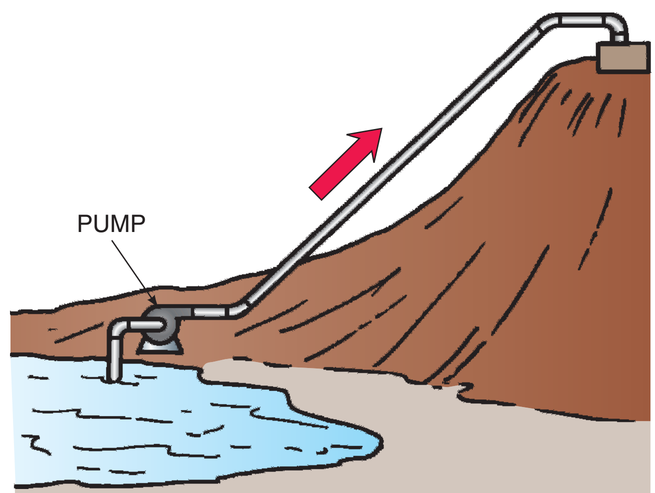


Figure 3–7 Power is required to pump water uphill. The same is true for pumping heat up the temperature scale from a 35°F box temperature to a 70°F room temperature.

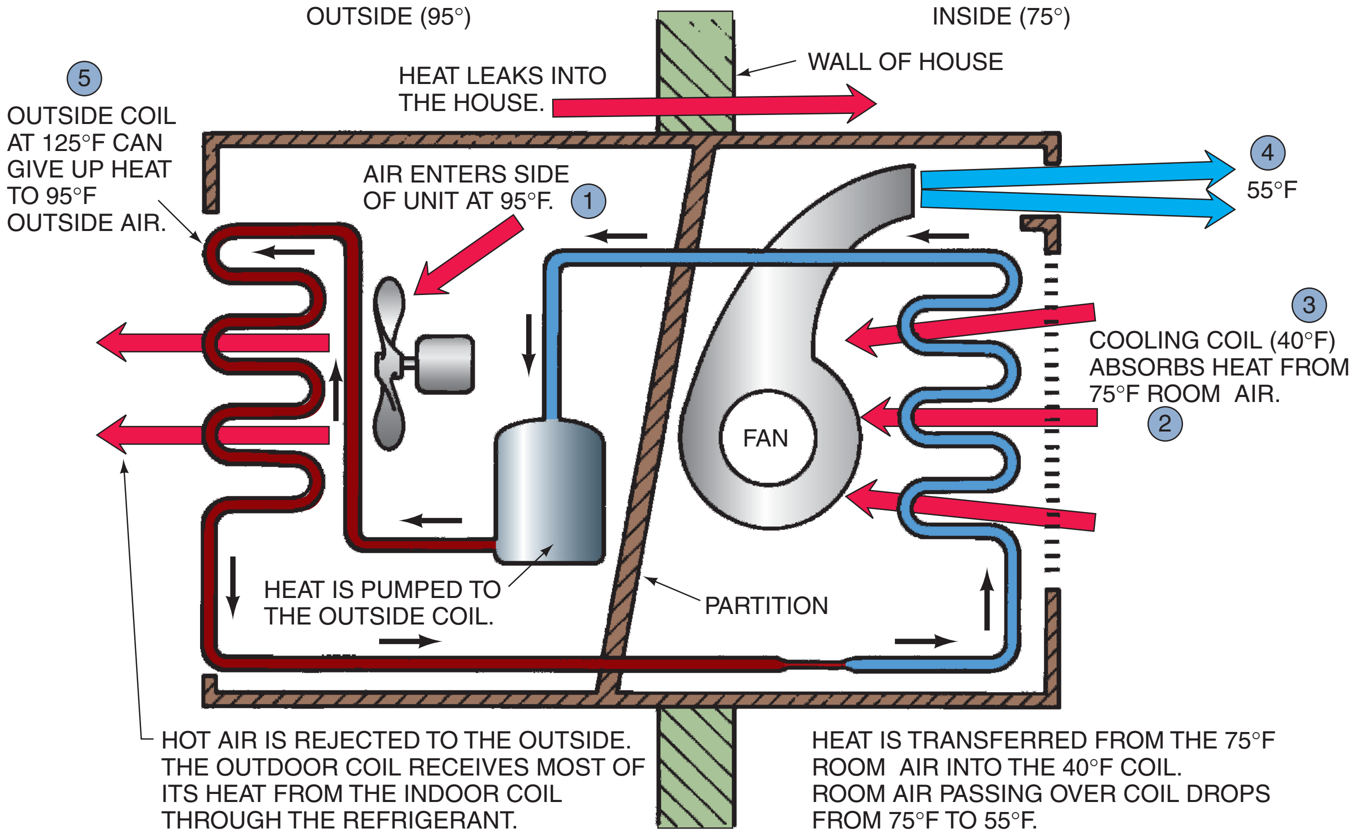


Figure 3–8 A window air-conditioning unit.

When heat enters the house, it must be removed. The heat is transferred outside by the air-conditioning system. The cold air in the house is recirculated air. Room air at approximately 75°F goes into the air-conditioning unit, and air at approximately 55°F comes out. This is the same air with some of the heat removed, **Figure 3–8.**

The following example illustrates this concept. The following statements are also guidelines to some of the design data used throughout the air-conditioning field.

1. The outside design temperature is 95°F.
2. The inside design temperature is 75°F.
3. The design cooling coil temperature is 40°F. This coil transfers heat from the room into the refrigeration system. Notice that with a 75°F room temperature and a 40°F cooling coil temperature, heat will transfer from the room air into the refrigerant in the coil.
4. This heat transfer makes the air leaving the coil and entering the fan about 55°F. The air exits the fan also at 55°F.
5. The outside coil temperature is 125°F. This coil transfers heat from the system to the outside air. Notice that when the outside air temperature is 95°F and the coil temperature is 125°F, heat will be transferred from the system to the outside air.

Careful examination of **Figure 3–8** shows that heat from the house is transferred into the refrigeration system through the inside coil and transferred to the outside air from the refrigeration system through the outside coil. The air-conditioning system is actually pumping the heat out of the house. The system capacity must be large enough to pump the heat out of the house faster than it is leaking back in so the occupants will not become uncomfortable.

3.5 TEMPERATURE AND PRESSURE RELATIONSHIP

To understand the refrigeration process, we must go back to **Figure 1–15** (heat/temperature graph), where water was changed to steam. Water boils at 212°F at 29.92 in. Hg pressure. This suggests that water has other boiling points. The next statement is one of the most important in this text. You may wish to memorize it. **The boiling point of water can be changed and controlled by controlling the vapor pressure above the water.** Understanding this concept is necessary because water is used as the heat transfer medium in the following example. The next few paragraphs are important for understanding refrigeration.

The *temperature/pressure relationship* correlates the vapor pressure and the boiling point of water and is the basis for controlling the system's temperatures. So, if we are able to control the pressures in a refrigeration or air-conditioning system, we will be able to control the temperatures that the system will maintain.

Pure water boils at 212°F at sea level when the barometric pressure is at the standard value of 29.92 in. Hg. This condition exerts an atmospheric pressure of 14.696 psia (0 psig) on the water's surface. This reference point is on the last line of the table in **Figure 3–9.** Also see **Figure 3–10,** showing the container

WATER TEMPERATURE °F	ABSOLUTE PRESSURE lb/in² (psia)	in. Hg
10	0.031	0.063
20	0.050	0.103
30	0.081	0.165
32	0.089	0.180
34	0.096	0.195
36	0.104	0.212
38	0.112	0.229
40	0.122	0.248
42	0.131	0.268
44	0.142	0.289
46	0.153	0.312
48	0.165	0.336
50	0.178	0.362
60	0.256	0.522
70	0.363	0.739
80	0.507	1.032
90	0.698	1.422
100	0.950	1.933
110	1.275	2.597
120	1.693	3.448
130	2.224	4.527
140	2.890	5.881
150	3.719	7.573
160	4.742	9.656
170	5.994	12.203
180	7.512	15.295
190	9.340	19.017
200	11.526	23.468
210	14.123	28.754
212	14.696	29.921

Figure 3–9 The boiling point of water. The temperature at which water will boil at a specified pressure can be found on the temperature/pressure chart for water.

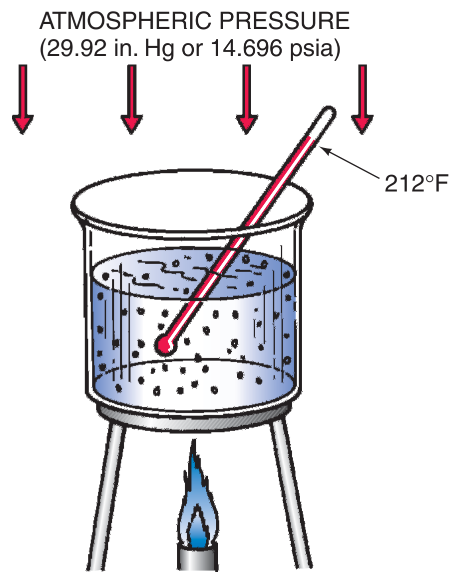


Figure 3–10 Water boils at 212°F when the atmospheric pressure is 29.92 in. Hg.

of water boiling at sea level at atmospheric pressure. When this same pan of water is taken to a mountaintop, the boiling point changes, **Figure 3–11,** because the thinner atmosphere causes a reduction in pressure (about 1 in. Hg/1000 ft). In Denver, Colorado, for example, which is about 5000 ft above sea level, the atmospheric pressure is approximately 25 in. Hg. Water boils at 203.4°F at that pressure. This makes cooking foods such as potatoes and dried beans more difficult because they now need more time to cook. But, by placing the food in a closed container that can be pressurized, such as a pressure cooker, and allowing the pressure to go up to about 15 psi above atmosphere (or 30 psia), the boiling point can be raised to 250°F, **Figure 3–12.**

Studying the water temperature/pressure table reveals that whenever the pressure is increased, the boiling point increases, and that whenever the pressure is reduced, the boiling point is reduced. If water were boiled at a temperature low enough to absorb heat out of a room, we could have comfort cooling (air conditioning).

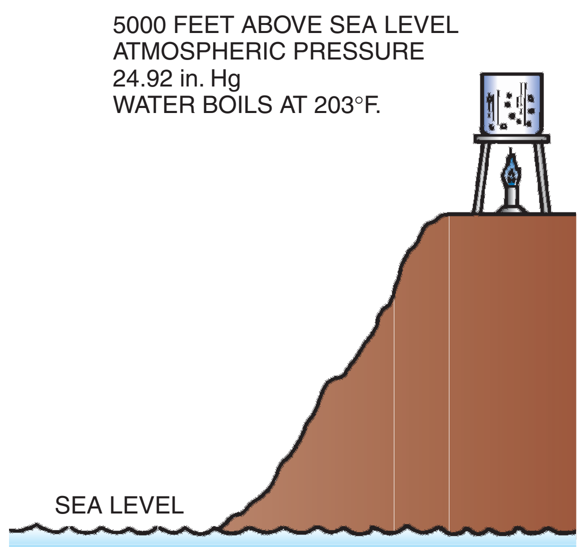


Figure 3–11 Water boils at 203°F when the atmospheric pressure is 24.92 in. Hg.

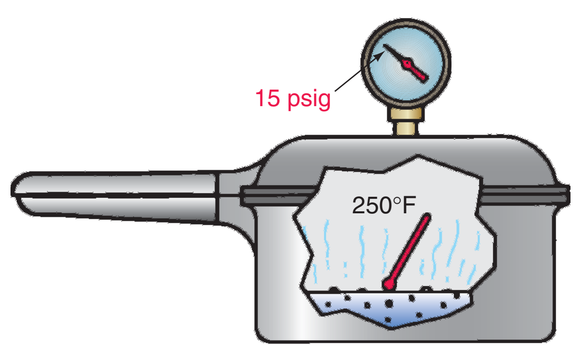


Figure 3–12 The water in a pressure cooker boils at 250°F. As heat is added, the water boils to make vapor. Since the vapor cannot escape, the vapor pressure rises to 15 psig. The water boils at a temperature higher than 212°F because the pressure in the vessel has risen to a level above atmospheric pressure.

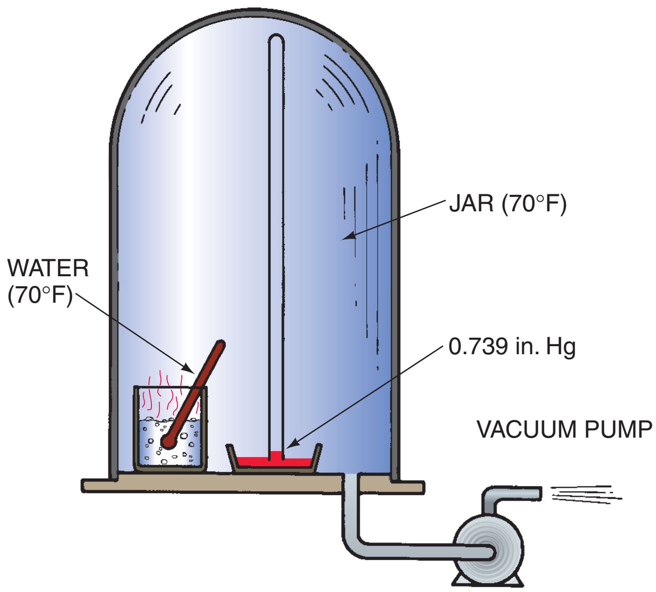


Figure 3–13 The pressure in the bell jar is reduced to 0.739 in. Hg. The boiling temperature of the water is reduced to 70°F because the pressure is 0.739 in. Hg (0.363 psia).

Let us place a thermometer in the pan of pure water, put the pan inside a bell jar with a barometer, and start the vacuum pump. Suppose the water is at room temperature (70°F). When the pressure in the jar reaches the pressure that corresponds to the boiling point of water at 70°F, the water will start to boil and vaporize. This point is 0.739 in. Hg (0.363 psia). **Figure 3–13** illustrates the container in the jar. These figures can be found in the table in **Figure 3–9.**

Notice that, in **Figure 3–9,** the temperatures are listed in the left-hand column and the pressures are found in the body of the chart, hence the name temperature/pressure chart (or table). Sometimes, however, the information is presented differently. On some charts, the pressures are located in the left-hand column and the temperatures are found in the body of the chart. These charts or tables are referred to as pressure/temperature charts. Although the information presented is the same, the way that it is presented is different. Make certain that you know which type of chart you are using—or inaccurate calculations and system conclusions may result.

If we were to lower the pressure in the jar to correspond to a temperature of 40°F, this new pressure of 0.248 in. Hg (0.122 psia) will cause the water to boil at 40°F. The water is not hot even though it is boiling. The thermometer in the pan indicates this. If the jar were opened to the atmosphere, the water would be found to be cold. Also, if the jar were opened to the atmosphere, the pressure in the jar would rise and the boiling process would stop.

Now let us circulate this water boiling at 40°F through a cooling coil. If room air were passed over it, it would absorb heat from the room air. Because this air is giving up heat to the coil, the air leaving the coil is cold. **Figure 3–14** illustrates the cooling coil.

When water is used in this way, it is called a *refrigerant.* **A *refrigerant* is a substance that can be changed readily to a vapor by boiling it and then changed to a liquid by condensing it.** The refrigerant must be able to make this change repeatedly without altering its characteristics. Water is not normally used as a refrigerant in small applications for reasons that will be discussed later. We used it in this example because most people are familiar with its characteristics.

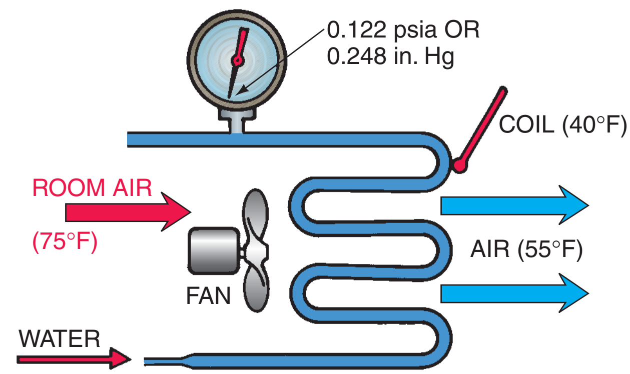


Figure 3–14 The water is boiling at 40°F because the pressure is 0.122 psia or 0.248 in. Hg. The room air is 75°F and gives up heat to the 40°F coil.

To explore how a real refrigeration system works, we will use refrigerant-22 (R-22) in the following examples because it is commonly used in residential air conditioning. See **Figure 3–15** for the temperature/pressure relationship chart for several refrigerants including R-22. This chart is like that for water but at different temperature and pressure levels. Take a moment to become familiar with this chart; observe that temperature is in the left column, expressed in °F, and pressure is to the right expressed in psig. Find 40°F in the left column, read to the right, and notice that the gage reading is 68.5 psig for R-22. What does this mean in usable terms? It means that when R-22 liquid is boiled at a vapor pressure of 68.5 psig, it will boil at a temperature of 40°F. When air is passed over the coil, it will cool just as in the example of water.

The pressure and temperature of a refrigerant will correspond when both liquid and vapor are present under two conditions:

1. When the change of state (boiling or condensing) is occurring.
2. When the refrigerant is at equilibrium (i.e., no heat is added or removed).

In both conditions 1 and 2, the refrigerant is said to be *saturated.* When a refrigerant is saturated, both liquid and vapor can exist simultaneously. When they do, both the liquid and the vapor will have the same saturation temperature. NOTE: The liquid and vapor being at the same temperature is not true for some of the newer blended refrigerants that have a temperature glide. Temperature glide will be covered in Unit 9. This saturation temperature depends on the pressure of the liquid/vapor mixture. This pressure is called the saturation pressure. The higher the pressure, the higher the saturation temperature of the liquid and vapor mixture. The lower the pressure, the lower the saturation temperature.

Suppose that a cylinder of R-22 is allowed to set in a room until it reaches the room temperature of 75°F. It will then be

TEMPERATURE °F	REFRIGERANT 12	22	134a	502	404A	410A
−60	19.0	12.0		7.2	6.6	0.3
−55	17.3	9.2		3.8	3.1	2.6
−50	15.4	6.2		0.2	0.8	5.0
−45	13.3	2.7		1.9	2.5	7.8
−40	11.0	0.5	14.7	4.1	4.8	9.8
−35	8.4	2.6	12.4	6.5	7.4	14.2
−30	5.5	4.9	9.7	9.2	10.2	17.9
−25	2.3	7.4	6.8	12.1	13.3	21.9
−20	0.6	10.1	3.6	15.3	16.7	26.4
−18	1.3	11.3	2.2	16.7	18.2	28.2
−16	2.0	12.5	0.7	18.1	19.6	30.2
−14	2.8	13.8	0.3	19.5	21.1	32.2
−12	3.6	15.1	1.2	21.0	22.7	34.3
−10	4.5	16.5	2.0	22.6	24.3	36.4
−8	5.4	17.9	2.8	24.2	26.0	38.7
−6	6.3	19.3	3.7	25.8	27.8	40.9
−4	7.2	20.8	4.6	27.5	30.0	42.3
−2	8.2	22.4	5.5	29.3	31.4	45.8
0	9.2	24.0	6.5	31.1	33.3	48.3
1	9.7	24.8	7.0	32.0	34.3	49.6
2	10.2	25.6	7.5	32.9	35.3	50.9
3	10.7	26.4	8.0	33.9	36.4	52.3
4	11.2	27.3	8.6	34.9	37.4	53.6
5	11.8	28.2	9.1	35.8	38.4	55.0
6	12.3	29.1	9.7	36.8	39.5	56.4
7	12.9	30.0	10.2	37.9	40.6	57.8
8	13.5	30.9	10.8	38.9	41.7	59.3
9	14.0	31.8	11.4	39.9	42.8	60.7
10	14.6	32.8	11.9	41.0	43.9	62.2
11	15.2	33.7	12.5	42.1	45.0	63.7

TEMPERATURE °F	REFRIGERANT 12	22	134a	502	404A	410A
12	15.8	34.7	13.2	43.2	46.2	65.3
13	16.4	35.7	13.8	44.3	47.4	66.8
14	17.1	36.7	14.4	45.4	48.6	68.4
15	17.7	37.7	15.1	46.5	49.8	70.0
16	18.4	38.7	15.7	47.7	51.0	71.6
17	19.0	39.8	16.4	48.8	52.3	73.2
18	19.7	40.8	17.1	50.0	53.5	75.0
19	20.4	41.9	17.7	51.2	54.8	76.7
20	21.0	43.0	18.4	52.4	56.1	78.4
21	21.7	44.1	19.2	53.7	57.4	80.1
22	22.4	45.3	19.9	54.9	58.8	81.9
23	23.2	46.4	20.6	56.2	60.1	83.7
24	23.9	47.6	21.4	57.5	61.5	85.5
25	24.6	48.8	22.0	58.8	62.9	87.3
26	25.4	49.9	22.9	60.1	64.3	90.2
27	26.1	51.2	23.7	61.5	65.8	91.1
28	26.9	52.4	24.5	62.8	67.2	93.0
29	27.7	53.6	25.3	64.2	68.7	95.0
30	28.4	54.9	26.1	65.6	70.2	97.0
31	29.2	56.2	26.9	67.0	71.7	99.0
32	30.1	57.5	27.8	68.4	73.2	101.0
33	30.9	58.8	28.7	69.9	74.8	103.1
34	31.7	60.1	29.5	71.3	76.4	105.1
35	32.6	61.5	30.4	72.8	78.0	107.3
36	33.4	62.8	31.3	74.3	79.6	108.4
37	34.3	64.2	32.2	75.8	81.2	111.6
38	35.2	65.6	33.2	77.4	82.9	113.8
39	36.1	67.1	34.1	79.0	84.6	116.0
40	37.0	68.5	35.1	80.5	86.3	118.3
41	37.9	70.0	36.0	82.1	88.0	120.5

TEMPERATURE °F	REFRIGERANT 12	22	134a	502	404A	410A
42	38.8	71.4	37.0	83.8	89.7	122.9
43	39.8	73.0	38.0	85.4	91.5	125.2
44	40.7	74.5	39.0	87.0	93.3	127.6
45	41.7	76.0	40.1	88.7	95.1	130.0
46	42.6	77.6	41.1	90.4	97.0	132.4
47	43.6	79.2	42.2	92.1	98.8	134.9
48	44.6	80.8	43.3	93.9	100.7	136.4
49	45.7	82.4	44.4	95.6	102.6	139.9
50	46.7	84.0	45.5	97.4	104.5	142.5
55	52.0	92.6	51.3	106.6	114.6	156.0
60	57.7	101.6	57.3	116.4	125.2	170.0
65	63.8	111.2	64.1	126.7	136.5	185.0
70	70.2	121.4	71.2	137.6	148.5	200.8
75	77.0	132.2	78.7	149.1	161.1	217.6
80	84.2	143.6	86.8	161.2	174.5	235.4
85	91.8	155.7	95.3	174.0	188.6	254.2
90	99.8	168.4	104.4	187.4	203.5	274.1
95	108.2	181.8	114.0	201.4	219.2	295.0
100	117.2	195.9	124.2	216.2	235.7	317.1
105	126.6	210.8	135.0	231.7	253.1	340.3
110	136.4	226.4	146.4	247.9	271.4	364.8
115	146.8	242.7	158.5	264.9	290.6	390.5
120	157.6	259.9	171.2	282.7	310.7	417.4
125	169.1	277.9	184.6	301.4	331.8	445.8
130	181.0	296.8	198.7	320.8	354.0	475.4
135	193.5	316.6	213.5	341.2	377.1	506.5
140	206.6	337.2	229.1	362.6	401.4	539.1
145	220.3	358.9	245.5	385.9	426.8	573.2
150	234.6	381.5	262.7	408.4	453.3	608.9
155	249.5	405.1	280.7	432.9	479.8	616.2

VACUUM (in. Hg) – RED FIGURES
GAGE PRESSURE (psig) – BOLD FIGURES

Figure 3–15 This chart shows the temperature/pressure relationship in in. Hg vacuum, or psig. Pressures for R-404A and R-410A are an average liquid and vapor pressure.

in equilibrium because no outside forces are acting on it. The cylinder and its partial liquid, partial vapor contents will now be at the room temperature of 75°F. The temperature and pressure chart indicates a pressure of 132 psig, **Figure 3–15.** This temperature/pressure chart is also referred to as a saturation chart because it contains saturation temperatures for different saturation pressures.

Suppose that the same cylinder of R-22 is moved into a walk-in cooler and allowed to reach the room temperature of 35°F and attain equilibrium. The cylinder will then reach a new pressure of 61.5 psig because while it is cooling off to 35°F, the vapor inside the cylinder is reacting to the cooling effect by partially condensing; therefore, the pressure drops.

If we move the cylinder (now at 35°F) back into the warmer room (75°F) and allow it to warm up, the liquid inside it reacts to the warming effect by boiling slightly and creating vapor. Thus, the pressure gradually increases to 132 psig, which corresponds to 75°F.

If we move the cylinder (now at 75°F) into a room at 100°F, the liquid again responds to the temperature change by slightly boiling and creating more vapor. As the liquid boils and makes vapor, the pressure steadily increases (according to the temperature/pressure chart) until it corresponds to the liquid temperature. This continues until the contents of the cylinder reach the pressure, 196 psig, corresponding to 100°F, **Figure 3–16, Figure 3–17,** and **Figure 3–18.**

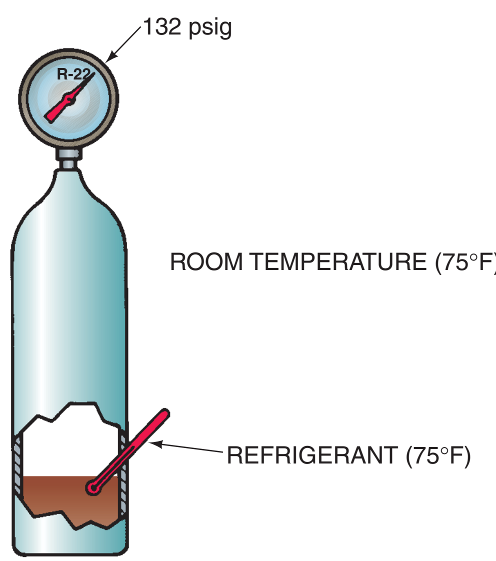


Figure 3–16 The cylinder of R-22 is left in a 75°F room until it and its contents are at room temperature. The cylinder contains a partial liquid, partial vapor mixture. When both reach room temperature, they are in equilibrium and no further temperature changes will occur. At this time, the cylinder pressure, 132 psig, will correspond to the ambient, or surrounding temperature of 75°F. The liquid and vapor refrigerant are said to be saturated at 75°F.

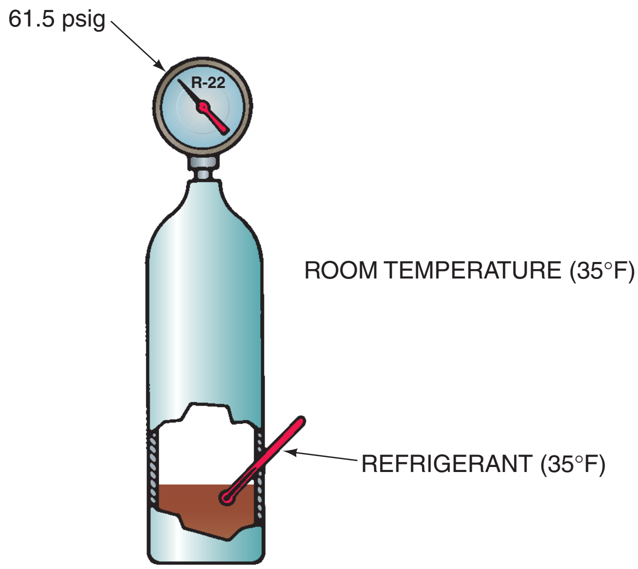


Figure 3–17 The cylinder of R-22 is moved into a 35°F walk-in cooler and left until the cylinder and its contents are at the same temperature as the cooler. As the refrigerant in the cylinder cools, some of the vapor will condense into a liquid, reducing the vapor pressure in the cylinder. Once the partial liquid, partial vapor mixture reaches the cooler temperature of 35°F, they are in equilibrium and no further temperature changes will occur. At this time, the cylinder pressure, 61.5 psig, will correspond to the cooler temperature of 35°F. The liquid and vapor refrigerant are now saturated at 35°F.

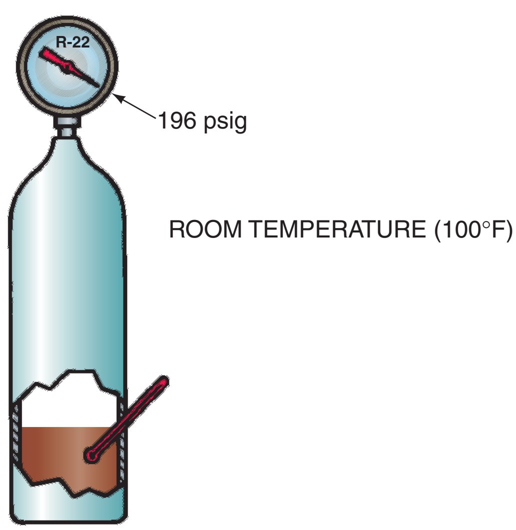


Figure 3–18 The cylinder of R-22 is moved to a 100°F room and allowed to reach the equilibrium point of 100°F and 196 psig. The rise in pressure is due to the fact that, at the higher temperature, some of the liquid refrigerant vaporizes. This causes the vapor pressure to increase. The liquid and vapor are still saturated but are now at a higher saturation temperature.

In fact, the vapor that was generated because of the increase in temperature is referred to as *vapor pressure*. Vapor pressure is the pressure exerted on a saturated liquid. Any time saturated vapor and liquid are together, vapor pressure is generated. Vapor pressure acts equally in all directions, and this action is what the pressure gage reads on a refrigeration or air-conditioning system. As the temperature of the liquid/vapor mixture increases, vapor pressure increases. As the temperature of the liquid/vapor mixture decreases, vapor pressure decreases.

Further study of the temperature/pressure chart shows that when the pressure is lowered to atmospheric pressure, R-22 boils at about −41°F. ♻ Do not perform the following exercises because allowing refrigerant to intentionally escape to the atmosphere is against the law! These are mentioned here for illustration purposes only. ♻ If the valve on the cylinder of R-22 were opened slowly and the vapor allowed to escape to the atmosphere, the pressure loss of the vapor would cause the liquid remaining in the cylinder to boil and drop in temperature. Whenever any liquid boils, heat is absorbed in the process, which causes a cooling effect. The heat in this case came from the R-22 liquid in the cylinder. Soon the pressure in the cylinder would be down to atmospheric pressure, and it would frost over and become −41°F. We are assuming that the vapor valve at the top of the R-22 cylinder is large enough to allow the R-22 vapor to escape freely. This way, the vapor will leave the cylinder at the same rate the R-22 liquid is boiling in the cylinder.

Now, let's say that we took one end of a gage hose and connected it to the liquid port of a refrigerant (R-22) cylinder and we directed the other end to a cup. If the liquid valve were opened very slowly, liquid refrigerant would flow from the cylinder, through the gage hose, and into the cup. The liquid refrigerant would accumulate in the cup and you might notice the liquid boiling. If a thermometer were placed in the cup of boiling refrigerant, the thermometer would register a reading of −41°F, **Figure 3–19.** You can double-check these numbers by looking up the saturation temperature for R-22 at 0 psig on the temperature/pressure chart. ♻ Again, do not perform the preceding experiments. ♻

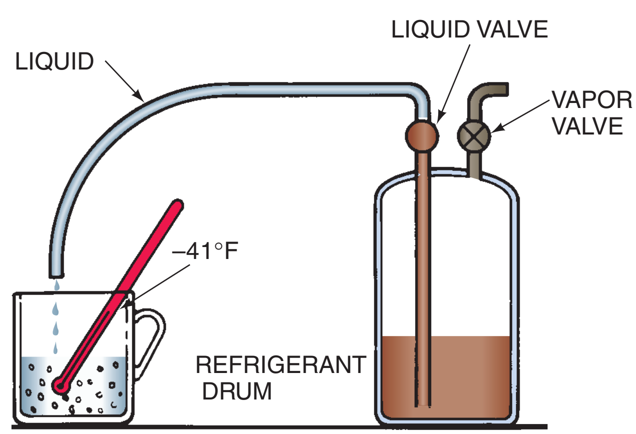


Figure 3–19 When the gage hose is attached to the liquid line valve on an R-22 cylinder and liquid is allowed to trickle out of it and into the cup, the liquid will collect in the cup. The liquid R-22 will continue to boil at a temperature of −41°F until all the liquid has vaporized. ♻ Do not perform this experiment because it is illegal to intentionally vent or release refrigerants to the atmosphere. ♻

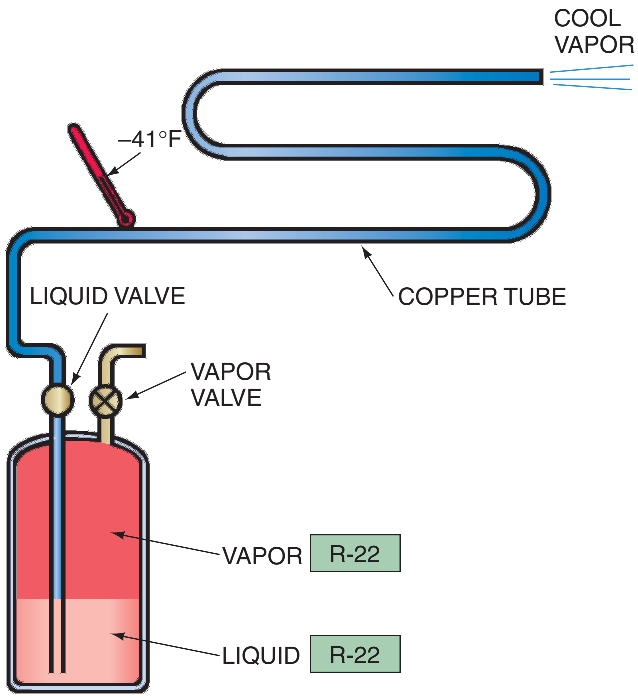


Figure 3–20 When the tubing is attached to the liquid line valve on an R-22 cylinder and liquid is allowed to trickle into the tubing, the liquid will boil at a temperature of −41°F at atmospheric pressure. ♻ Do not perform this experiment as it is illegal to intentionally vent or release refrigerants to the atmosphere. ♻

A crude but effective demonstration has been used in the past to show how air can be cooled. ♻ Do not perform this experiment because intentionally venting refrigerant to the atmosphere is illegal. ♻ A long piece of copper tubing is fastened to the liquid tap on the refrigerant cylinder, and liquid refrigerant is allowed to trickle into the tube while air passes over it. The tube has a temperature of −41°F, corresponding to atmospheric pressure, because the refrigerant is escaping out of the end of the tube at atmospheric pressure. If the tube were coiled up and placed in an airstream, it would cool the air, **Figure 3–20.**

3.6 REFRIGERATION COMPONENTS

By adding some components to the system, these problems can be eliminated. The four major components that make up mechanical refrigeration systems are the following:

1. The evaporator
2. The compressor
3. The condenser
4. The refrigerant metering device

3.7 THE EVAPORATOR

The *evaporator* absorbs heat into the system. When the refrigerant is boiled at a lower temperature than that of the substance to be cooled, it absorbs heat from the substance. The boiling temperature of 40°F was chosen in the previous

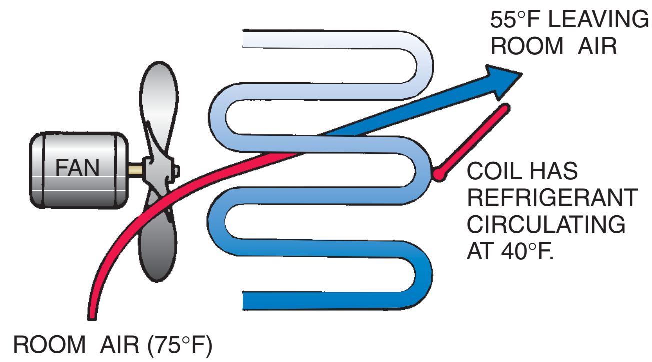


Figure 3–21 The evaporator is operated at 40°F to be able to absorb heat from the 75°F air.

air-conditioning examples because it is the design temperature normally used for air-conditioning systems. The reason is that the ideal room temperature is close to 75°F, which readily gives up heat to a 40°F coil. The 40°F temperature is also well above the freezing point of the coil. See **Figure 3–21** for the coil-to-air relationships.

The evaporator can be thought of as a "heat sponge." Just as a dry kitchen sponge absorbs liquid from a spill because the water content of the sponge is low, the evaporator is able to absorb heat because the temperature of the coil is lower than the temperature of the medium being cooled. Continuing our analogy, the sponge will stop absorbing liquid if it becomes completely soaked. This is why we have to squeeze the sponge to remove the absorbed water. Looking back at our evaporator, if we just keep adding heat to the coil, its temperature will rise and the amount of heat it can absorb will drop. So, the heat that is absorbed into the evaporator must be removed later on to allow the system to continue to operate.

Let us see what happens as the R-22 refrigerant passes through the evaporator coil. The refrigerant enters the coil from the bottom as a mixture of about 75% liquid and 25% vapor. These percentages can change because they are system and application dependent and will be a topic of later discussion. Evaporators are usually fed from the bottom to help ensure that no liquid leaves the top without first boiling off to a vapor. If they were fed from the top, liquid could quickly drop by its own weight to the bottom before it is completely boiled off to a vapor. This protects the compressor from any liquid refrigerant. In addition, vapor is less dense than liquid and, as the liquid refrigerant boils, the vapor has a tendency to rise. Since the refrigerant enters the coil from the bottom and leaves from the top, the direction of refrigerant flow is from the bottom to the top. This is the same direction as the direction of the rising vapor. If the refrigerant entered the evaporator from the top and left through the bottom, the direction of flow would be opposite to that of the rising vapor. This would cause the refrigerant to slow down.

The mixture is tumbling and boiling as it flows through the tubes, with the liquid being turned to vapor all along the coil because heat is being added to the coil from the air, **Figure 3–22.** About halfway down the coil, the mixture becomes more vapor than liquid. The purpose of the evaporator is to boil all of the liquid into a vapor just before the end of

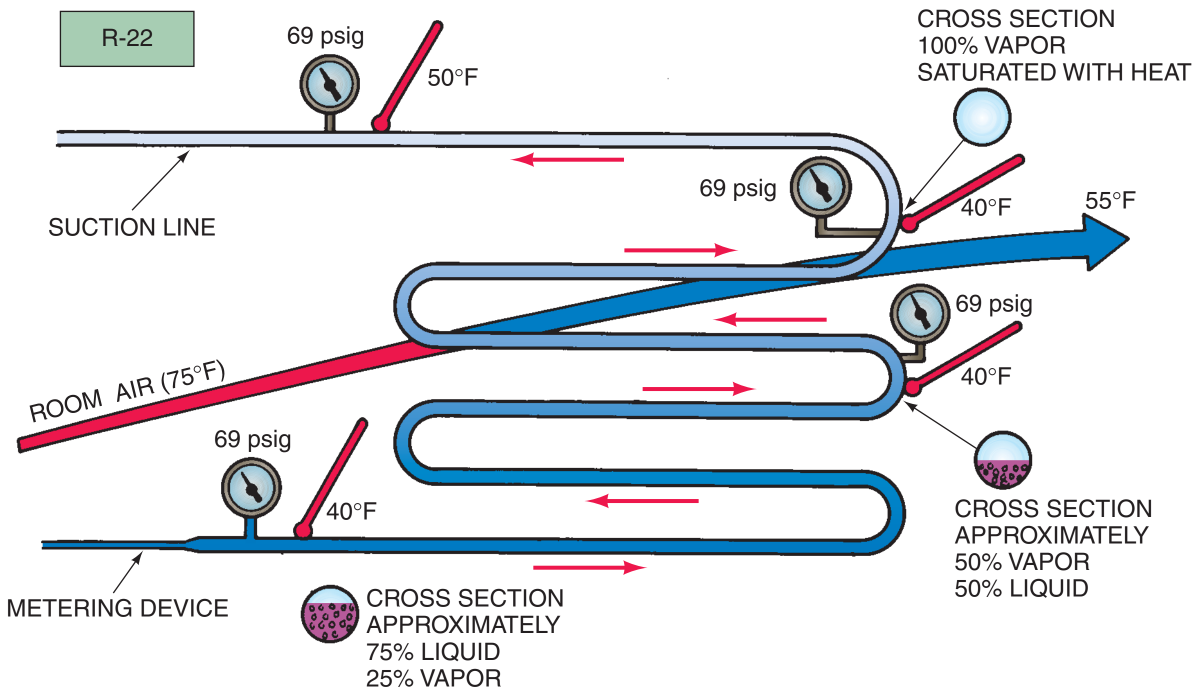


Figure 3–22 The evaporator absorbs heat into the refrigeration system by boiling the refrigerant at a temperature that is lower than the temperature of the room air passing over it. The 75°F room air readily gives up heat to the 40°F evaporator by conduction.

the coil. This occurs approximately 90% of the way through the coil, leaving pure vapor. At the point where the last droplet of liquid vaporizes, we have what is called a saturated vapor. This is the point where the vapor would start to condense if heat were removed from it or become superheated if any heat were added to it. ***When a vapor is superheated, it no longer corresponds to a temperature/pressure relationship. Because no liquid remains to boil off to vapor, no more vapor pressure can be generated when heat is added. The vapor will now take on sensible heat when heated, and its temperature will rise, but the pressure will remain unchanged.*** Superheat is considered insurance for the compressor because it ensures that no liquid leaves the evaporator and enters the compressor. When there is superheat, there is no liquid.

To summarize, the three main functions of the evaporator are to:

1. absorb heat from the medium being cooled.
2. allow the heat to boil off the liquid refrigerant to a vapor in its tubing bundle.
3. allow the heat to superheat the refrigerant vapor in its tubing bundle.

Evaporators have many design configurations. But for now just remember that they absorb the heat into the system from the substance to be cooled. The substance may be solid, liquid, or gas, and the evaporator has to be designed to fit the condition. See **Figure 3–23** for a typical evaporator. Once absorbed into the system, the heat is now contained in the refrigerant and is drawn into the compressor through the suction line. The suction line simply connects the evaporator to the compressor and provides a path for refrigerant vapor to travel, **Figure 3–24.** The suction line typically passes through unrefrigerated spaces and the surrounding air temperature is much higher than the temperature of the refrigerant line. Heat from the surrounding air can, therefore, be readily absorbed into the refrigeration system, making the system work much harder than needed. For this reason, the suction line is insulated, **Figure 3–25.** A well-insulated suction line helps the system operate as efficiently as possible.

Figure 3–23 A typical refrigeration evaporator. *Courtesy Ferris State University. Photo by Eugene Silberstein*

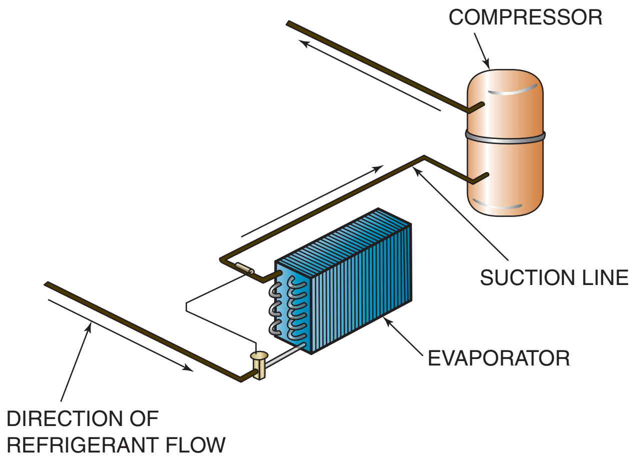


Figure 3–24 The suction line connects the outlet of the evaporator to the inlet of the compressor.

Figure 3–25 Suction lines should be well insulated to increase system efficiency and capacity. *Courtesy Ferris State University. Photo by John Tomczyk*

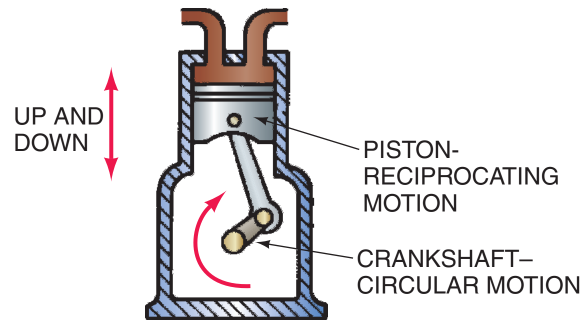


Figure 3–26 The crankshaft converts the circular, rotating motion of the motor to the reciprocating, or back-and-forth, motion of the piston.

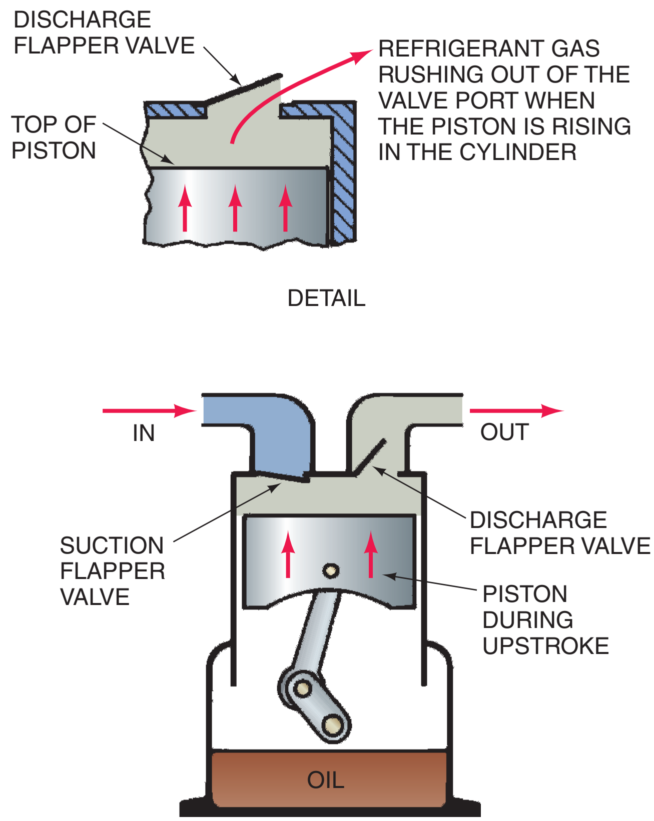


Figure 3–27 Flapper valves and compressor components.

3.8 THE COMPRESSOR

The compressor is the heart of the refrigeration system. It pumps heat through the system in the form of heat-laden refrigerant. A compressor can be considered a *vapor pump.* It reduces the pressure on the low-pressure side of the system, which includes the evaporator, and increases the pressure on the high-pressure side of the system. This pressure difference is what causes the refrigerant to flow through the system. All compressors in refrigeration systems perform this function by compressing the vapor refrigerant. This compression can be accomplished in several ways with different types of compressors. The most common compressors used in residential and light commercial air conditioning and refrigeration are the *reciprocating,* the *rotary,* and the *scroll.*

The reciprocating compressor uses a piston in a cylinder to compress the refrigerant, **Figure 3–26.** Valves, usually reed or flapper valves, ensure that the refrigerant flows in the correct direction, **Figure 3–27.** This compressor is known as a positive displacement compressor. Positive displacement compressors increase the pressure of the refrigerant by physically decreasing the volume of the container that is holding the refrigerant. In the case of the reciprocating compressor, the volume is decreased as the piston moves up in the cylinder. When the cylinder is filled with vapor, it must be emptied as the compressor turns, or damage will occur. For many years, it was the most commonly used compressor for systems up to 100 hp. Newer and more efficient designs of compressors are now being used.

The rotary compressor is also a positive displacement compressor and is used for applications that are typically in the small equipment range, such as window air conditioners, household refrigerators, and some residential air-conditioning systems. These compressors are extremely efficient and have few moving parts, **Figure 3–28.** This compressor uses a rotating drumlike piston that squeezes the refrigerant vapor out the discharge port. These compressors are typically very

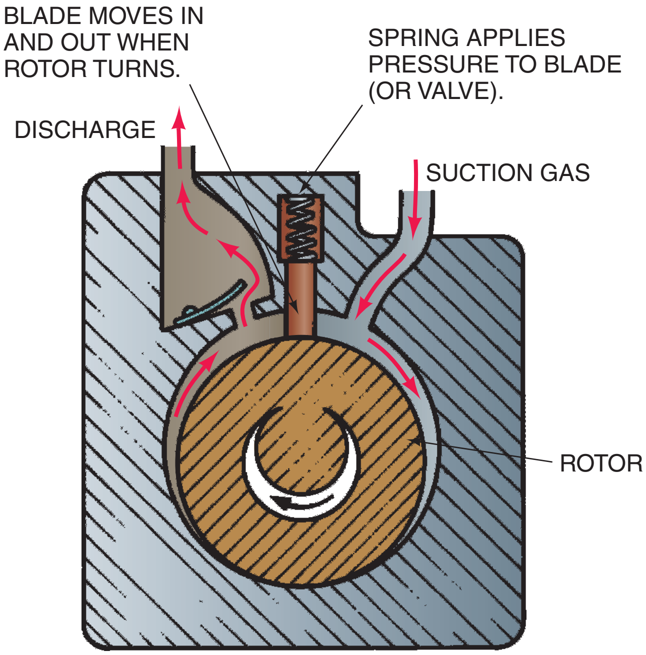


Figure 3–28 A rotary compressor with motion in one direction and no backstroke.

small compared with the same capacity of reciprocating compressors.

The scroll compressor is one of the latest compressors to be developed and has an entirely different working mechanism. It has a stationary part that looks like a coil spring and a moving part that matches and meshes with the stationary part, **Figure 3–29.** The movable part orbits inside the stationary part and squeezes the vapor from the low-pressure side to the high-pressure side of the system between movable and stationary parts. Several stages of compression are taking place in the scroll at the same time, making it a very smooth running compressor with few moving parts. The scroll is sealed on the bottom and top with the rubbing action and at the tip with a tip seal. These sealing surfaces prevent refrigerant from the high-pressure side from pushing back to the low-pressure side while running. It is a positive displacement compressor with a limitation. It is positive displacement until too much pressure differential builds up; then the scrolls are capable of moving apart, and high-pressure refrigerant can blow back through the compressor and prevent overload. This ability to move the mating scrolls apart makes it more forgiving if a little liquid refrigerant enters the compressor's inlet. Thus, compressor damage is less likely to occur.

Recent advances in computer-aided manufacturing techniques have enabled the scroll compressor to gain popularity in air conditioning and high-, medium-, and low-temperature refrigeration applications. The capacity of the scroll compressor can be controlled by the size and wall height of the orbiting and stationary (spirals) scrolls.

Large commercial systems use other types of compressors because they must move much more refrigerant vapor through the system. The centrifugal compressor is used in large air-conditioning systems. It is much like a large fan and is not positive displacement, **Figure 3–30.** The centrifugal

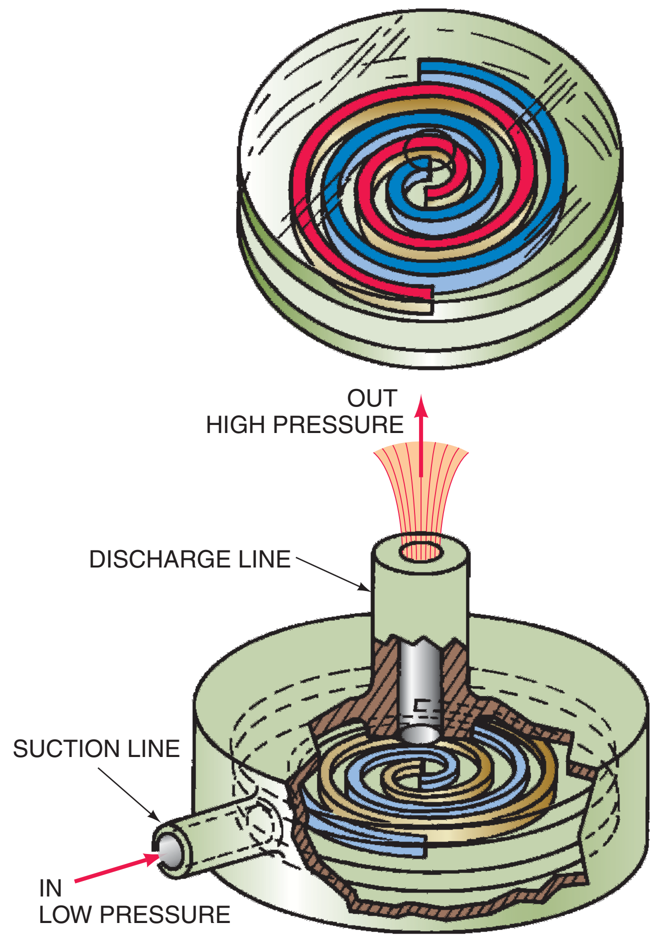


Figure 3–29 An illustration of the operation of a scroll compressor mechanism.

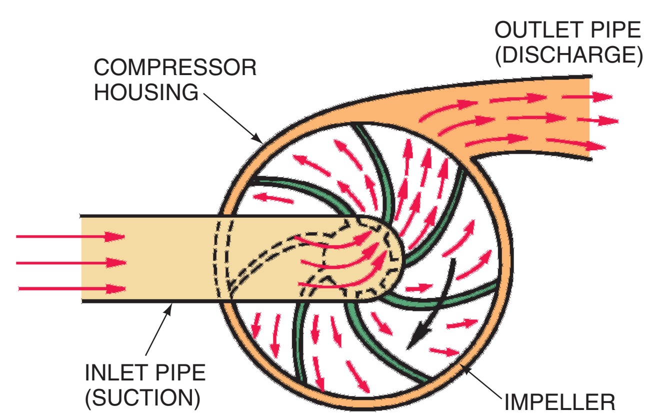


Figure 3–30 An illustration of the operation of a centrifugal compressor mechanism.

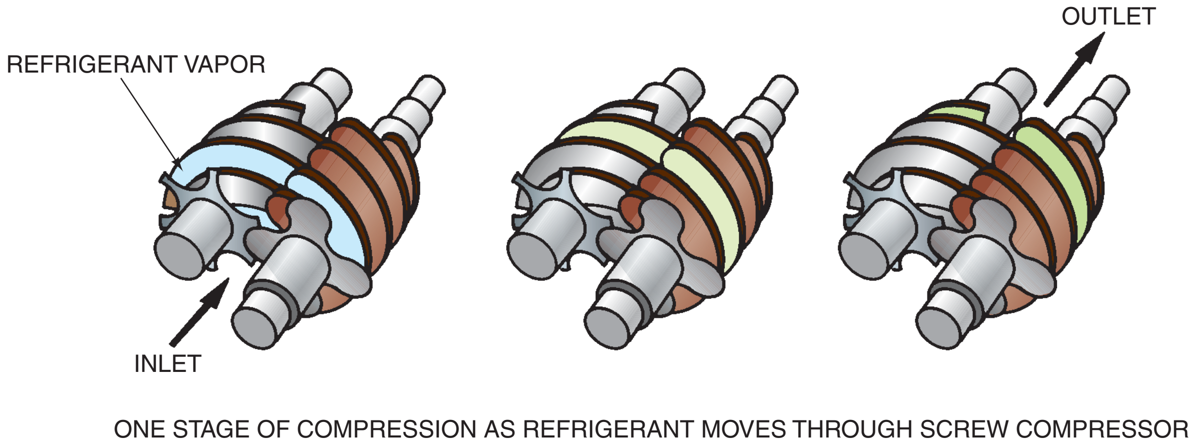


Figure 3–31 An illustration of the internal working mechanism of a screw compressor.

compressor is referred to as a *kinetic displacement compressor.* These compressors increase the kinetic energy of the refrigerant vapor with the high-speed fan and then convert this energy to a higher pressure. This technology is also used in jet engines.

The screw compressor is another positive displacement compressor and is used for larger air-conditioning and refrigeration applications. The compressor is made up of two nesting "screws," **Figure 3–31.** There is a space between the screws that gets smaller and smaller as we move from one end to the other. The vapor refrigerant enters the compressor at the point where the screw spacing is the widest. As the refrigerant flows between these rotating screws, the volume is reduced and the pressure of the vapor increases. The screw compressor is popular for use in low-temperature refrigeration applications.

The important thing to remember is that a compressor performs the same function no matter what the type is. For now it can be thought of as a component that increases the pressure in the system and moves the vapor refrigerant from the low-pressure side to the high-pressure side into the condenser.

3.9 THE CONDENSER

The *condenser* rejects both sensible (measurable) and latent (hidden) heat from the refrigeration system. This heat can come from what the evaporator has absorbed, any heat of compression or mechanical friction generated in the compression stroke, motor-winding heat, and any heat absorbed by superheating the refrigerant in the suction line before it enters the compressor.

The condenser receives the hot gas after it leaves the compressor through the short pipe between the compressor and the condenser; this pipe is called the hot gas line, **Figure 3–32.** This line is also referred to as the *discharge line.* The hot gas is forced into the top of the condenser coil by the compressor. The discharge gas from the compressor is a high-pressure, high-temperature, superheated vapor. The temperature of the hot gas from the compressor can be in the 200°F range and will change depending on the surrounding temperatures and the system application. The refrigerant at the outlet of the compressor DOES NOT follow a temperature/pressure relationship. This is because the refrigerant is 100% vapor and superheated. The high-side pressure reading of 278 psig in **Figure 3–33** corresponds to the 125°F condenser saturation temperature, which is the temperature at which the refrigerant will begin to condense from a vapor into a liquid. The

Figure 3–32 The discharge line connects the outlet of the compressor to the inlet of the condenser. *Courtesy Ferris State University. Photo by Eugene Silberstein*

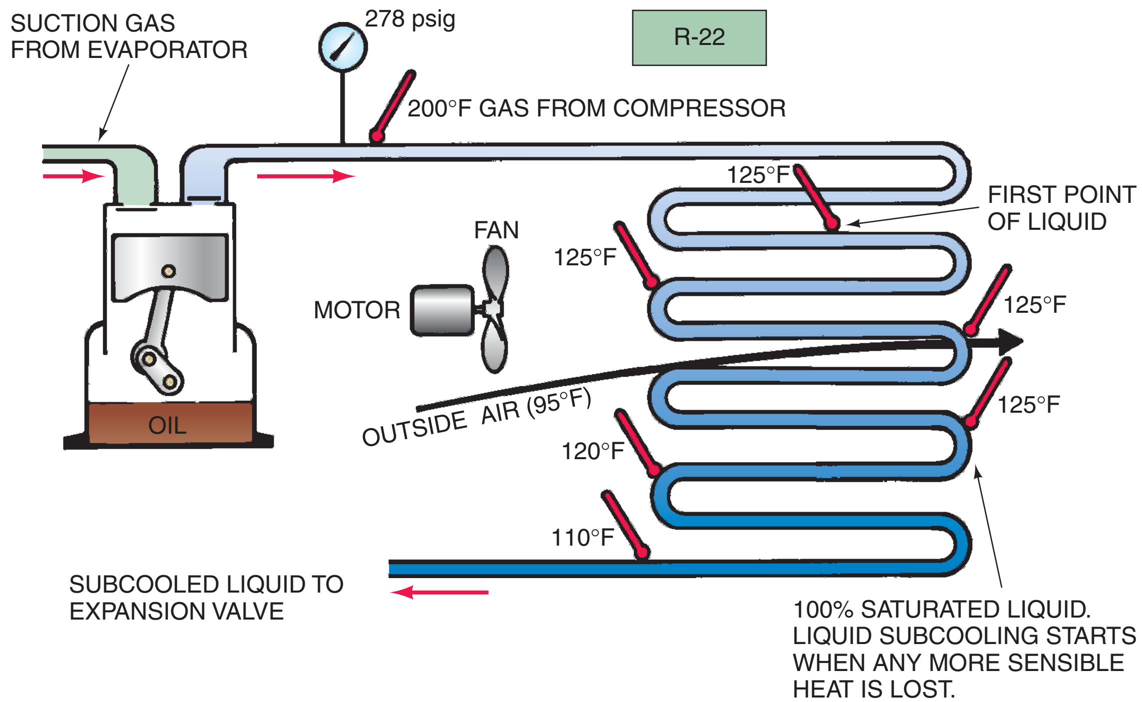


Figure 3–33 Subcooled liquid at the outlet of the condenser.

condenser is where the vapor pressure of 278 psig is actually coming from for the high-side gage to read. This vapor pressure is often referred to as head pressure, high-side pressure, discharge pressure, or condensing pressure in the heating, ventilation, air-conditioning, and refrigeration (HVACR) industry. The 200°F hot gas temperature coming out of the compressor is superheated by 75°F (200°F − 125°F) and again cannot have a temperature/pressure relationship. Therefore, the hot vapor must first cool, or desuperheat, 75 degrees before it can begin to condense.

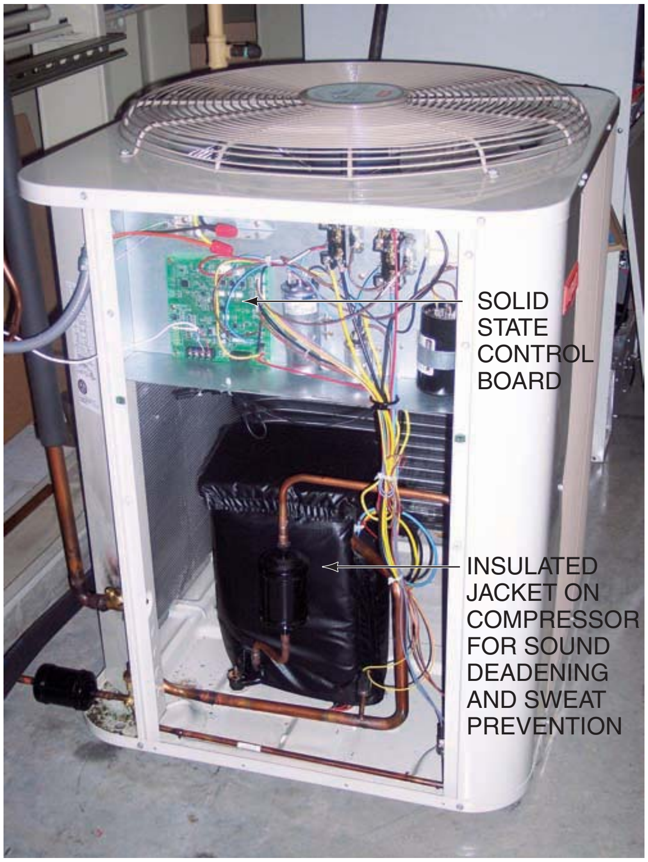
The gas leaving the compressor, flowing through the discharge line, and entering the condenser is so hot compared with the surrounding air that a heat exchange between the hot gas and the surrounding air begins to occur immediately. The surrounding air that is being passed over the condenser is 95°F as compared with the near 200°F gas entering the condenser. As the gas moves through the condenser, it begins to give up sensible heat to the surrounding air. This causes a drop in gas temperature. The gas keeps cooling off, or *desuper-heating*, until it reaches the condensing temperature of 125°F. Then, the change of state begins to occur. The change of state begins slowly at first with small amounts of vapor changing to liquid and gets faster as the vapor-liquid mixture moves through the condenser. This change of state from vapor to liquid happens at the condensing saturation temperature and pressure of 125°F and 278 psig, respectively. This change of state is a latent heat process, meaning that even though heat in Btu is being rejected from the refrigerant, the temperature is staying constant at 125°F. NOTE: This constant temperature process occurring during the change of state does not occur for some of the newer blended refrigerants that have a temperature glide.

When the condensing refrigerant gets about 90% of the way through the condenser, the refrigerant in the pipe becomes pure saturated liquid. If any more heat is removed from the 100% saturated liquid, the liquid will now go through a sensible-heat rejection process because no more vapor is left to condense. This causes the liquid to drop below the condensing saturation temperature of 125°F. Liquid cooler than the condensing saturation temperature is called *subcooled* liquid, **Figure 3–33.**

Three important things may happen to the refrigerant in the condenser:

1. The hot gas from the compressor is desuperheated from the hot discharge temperature to the condensing temperature. Remember, the condensing temperature determines the head pressure. This is sensible heat transfer.
2. The refrigerant is condensed from a vapor to a liquid. This is latent heat transfer.
3. The liquid refrigerant temperature may then be lowered below the condensing temperature, or subcooled. The refrigerant can usually be subcooled to between 10°F and 20°F below the condensing temperature, but is system dependent, **Figure 3–33.** This is a sensible heat transfer.

Many types of condensing devices are available. The condenser is the component that rejects the heat out of the refrigeration system. The heat may have to be rejected into a solid, liquid, or gas substance, and a condenser can be designed to do the job. Very often, the condenser and the compressor are incorporated into a single piece of equipment called a *condensing unit.* **Figure 3–34** shows some typical condensing units.



(A)

(B)

Figure 3–34 **(A)** Typical air-cooled condensing unit found on a split-type central air-conditioning system. **(B)** An air-cooled hermetic condensing unit from a refrigeration system. ***(A)*** *Courtesy Ferris State University. Photo by Eugene Silberstein.* ***(B)*** *Photo by Bill Johnson*

By incorporating both of these components into a single unit, system installation becomes an easier task. The suction line carries low-pressure, low-temperature superheated vapor to the condensing unit and the liquid line carries high-pressure, high-temperature subcooled liquid from the condensing unit to the metering device.

3.10 THE REFRIGERANT METERING DEVICE

The warm subcooled liquid is now moving down the liquid line in the direction of the *metering device*. The liquid temperature is about 110°F and may still give up some heat to the surroundings before reaching the metering device. This line may be routed under a house or through a wall where it may easily reach a new temperature of about 105°F. Any heat given off to the surroundings is helpful because it came from within the system and will help improve the system capacity and efficiency. It also brings the subcooled liquid temperature closer to the evaporator's saturation temperature, which also increases system capacity.

One type of metering device is a simple fixed-size (*fixed-bore*) type known as an *orifice*. It is a small restriction of a fixed size in the line, **Figure 3–35.** This device holds back the full flow of refrigerant and is one of the dividing points between the high-pressure and the low-pressure sides of the system. Only pure liquid must enter it. The pipe leading to the orifice may be the size of a pencil, and the precision-drilled hole in the orifice may be the size of a very fine sewing needle. As you can see from the figure, the liquid flow is greatly restricted here. For an R-22 system, the liquid refrigerant entering the orifice is at a pressure of 278 psig; the refrigerant leaving the orifice is a *mixture* of about 75% liquid and 25% vapor at a new pressure of 70 psig and a new temperature of 41°F, **Figure 3–35.** Two questions usually arise at this time:

1. Why did approximately 25% of the liquid change to a gas?
2. How did the mixture of 100% pure liquid go from about 105°F to 41°F in such a short space?

These questions can be answered by using a garden hose under pressure, in which the water coming out feels cooler, **Figure 3–36.** The water actually is cooler because some of it evaporates and turns to mist. This evaporation takes heat out of the rest of the water and cools it down. Now when the high-pressure subcooled refrigerant passes through the orifice, it does the same thing as the water in the hose; it changes pressure (278 psig to 70 psig), and some of the refrigerant flashes to a vapor (called *flash gas*). At this point, the refrigerant is a saturated mixture of liquid and vapor at 70 psig. Since the refrigerant is saturated, it follows the

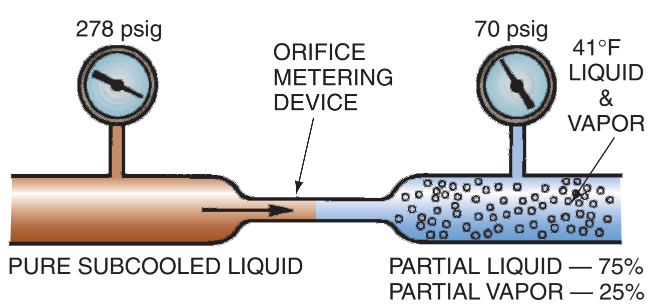
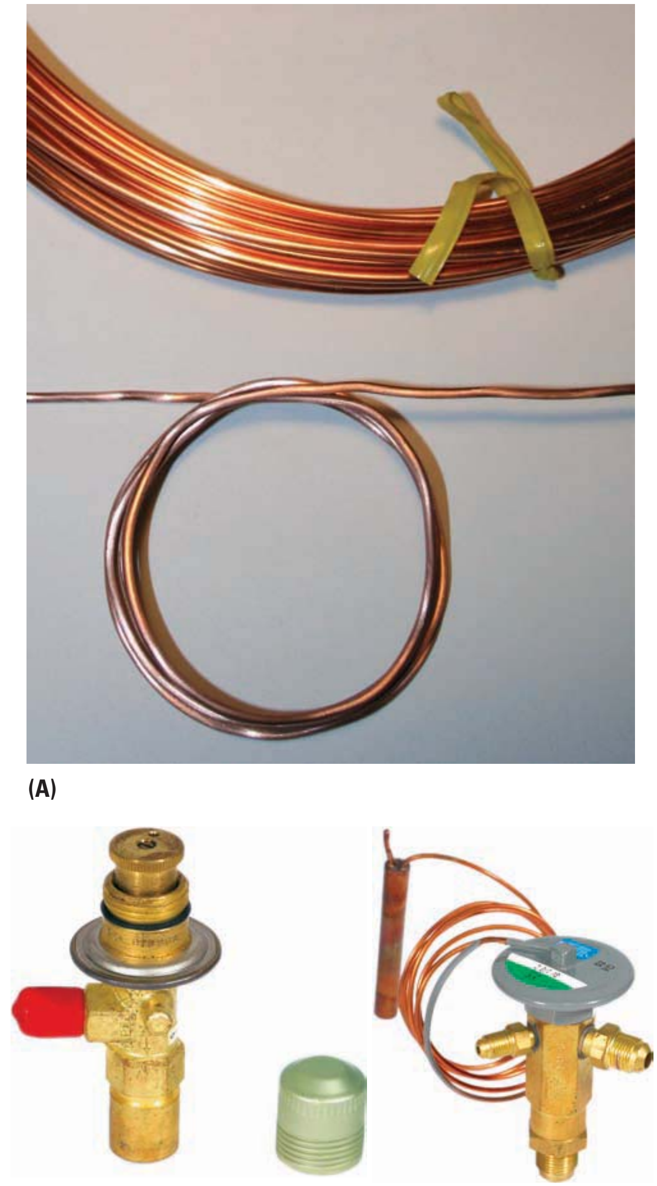


Figure 3–35 A fixed-bore (orifice) metering device on an R-22 system.

Figure 3–36 A person squeezing the end of a garden hose.

temperature/pressure relationship for that refrigerant—hence, the 41°F refrigerant temperature at the outlet of the metering device. In addition, the evaporating refrigerant further cools the liquid refrigerant that remains as the refrigerant flows through the metering device. *Flash gas* at the exit of the metering device is considered a loss to the system's capacity. This is because less liquid is now available to boil to vapor in the evaporator when cooling the refrigerated space. Because of this, flash gas should be kept to a minimum. This quick drop in pressure in the metering device lowers the boiling point or saturation temperature of the liquid leaving the metering device.

Several types of metering devices are available for many applications. They will be covered in detail in later units. See **Figure 3–37** for some examples of the various types of metering devices.



(A)

(B) (C)

Figure 3–37 Metering devices. **(A)** Capillary tube. **(B)** Automatic expansion valve. **(C)** Thermostatic expansion valve. ***(A)*** *Courtesy Ferris State University. Photo by John Tomczyk.* ***(B)*** *and* ***(C)*** *Photos by Bill Johnson*

3.11 REFRIGERATION SYSTEM AND COMPONENTS

The basic components of the mechanical, vapor-compression refrigeration system have been described according to function. These components must be properly matched for each specific application. For instance, a low-temperature compressor cannot be applied to a high-temperature application because of the pumping characteristics of the compressor. Some equipment can be mixed and matched successfully by using the manufacturer's data, but only someone with considerable knowledge and experience should do so.

Following is a description of a matched system correctly working at design conditions. Later we will explain malfunctions and adverse operating conditions.

A typical air-conditioning system operating at a design temperature of 75°F inside temperature has a relative humidity (moisture content of the conditioned room air) of 50%. These conditions are to be maintained inside the house. The air in the house gives up heat to the refrigerant. The humidity factor has been brought up at this time because the indoor coil is also responsible for removing some of the moisture from the air to keep the humidity at an acceptable level. This is known as *dehumidifying*.

Moisture removal requires considerable energy. Approximately the same amount (970 Btu) of latent heat removal is required to condense a pound of water vapor from the air as to condense a pound of steam. All air-conditioning systems must have a method for dealing with this moisture after it has turned to a liquid. Some units drip, some drain the liquid into

plumbing waste drains, some use a slinger ring on the condenser fan, and some use the liquid at the outdoor coil to help the system capacity by evaporating it at the condenser.

Remember that part of the system is inside the house and part of the system is outside the house. The numbers in the description correspond to the circled numbers in **Figure 3–38.**

1. A mixture of 75% liquid and 25% vapor leaves the metering device and enters the evaporator.
2. The mixture is saturated R-22 at a pressure of 69 psig, which corresponds to a 40°F boiling point. It is important to remember that *the pressure is 69 psig because the evaporating refrigerant is boiling at 40°F.*
3. The mixture tumbles through the tube in the evaporator with the liquid evaporating from the 75°F inside air's heat and humidity load as it moves along.
4. When the mixture is about halfway through the coil, the refrigerant is composed of about 50% liquid and 50% vapor and is still at the same temperature and pressure because a change of state is taking place. Remember that this is a latent heat transfer.
5. The refrigerant is now 100% vapor. In other words, it has reached the 100% *saturation* point of the vapor. Recall the example using the saturated water table; the water reached various points where it was saturated with heat. We say it is saturated with heat because if any heat is removed at this point, some of the vapor changes back to a liquid; if any heat is added, the temperature of the vapor rises. This rise in temperature of the vapor makes it a *superheated* vapor. (Superheat is sensible heat.) At point 5, the saturated vapor is still at 40°F and still able to absorb more heat from the 75°F room air.
6. Pure vapor now exists that is normally superheated about 10°F above the saturation temperature. Examine the line in **Figure 3–38** at this point, and you will see that the temperature is about 50°F. NOTE: To arrive at the correct superheat reading at this point, take the following steps.
   - **A.** Note the suction pressure or evaporating pressure reading from the suction, or low-side, gage: 69 psig.
   - **B.** Convert the suction pressure reading to suction or evaporating temperature using the temperature/pressure chart for R-22: 40°F.
   - **C.** Use a suitable thermometer to record the actual temperature of the suction line at the outlet of the evaporator: 50°F.
   - **D.** Subtract the saturated suction temperature from the actual suction line temperature: 50°F − 40°F = 10°F of superheat.

   This vapor is said to be heat laden because it contains the heat removed from the room air. The heat was absorbed into the vaporizing refrigerant that boiled off to this vapor as it traveled through the evaporator. The vapor superheats another 10°F and is now 60°F as it travels down the suction line to the compressor. The superheat that is picked up only in the evaporator is referred to as

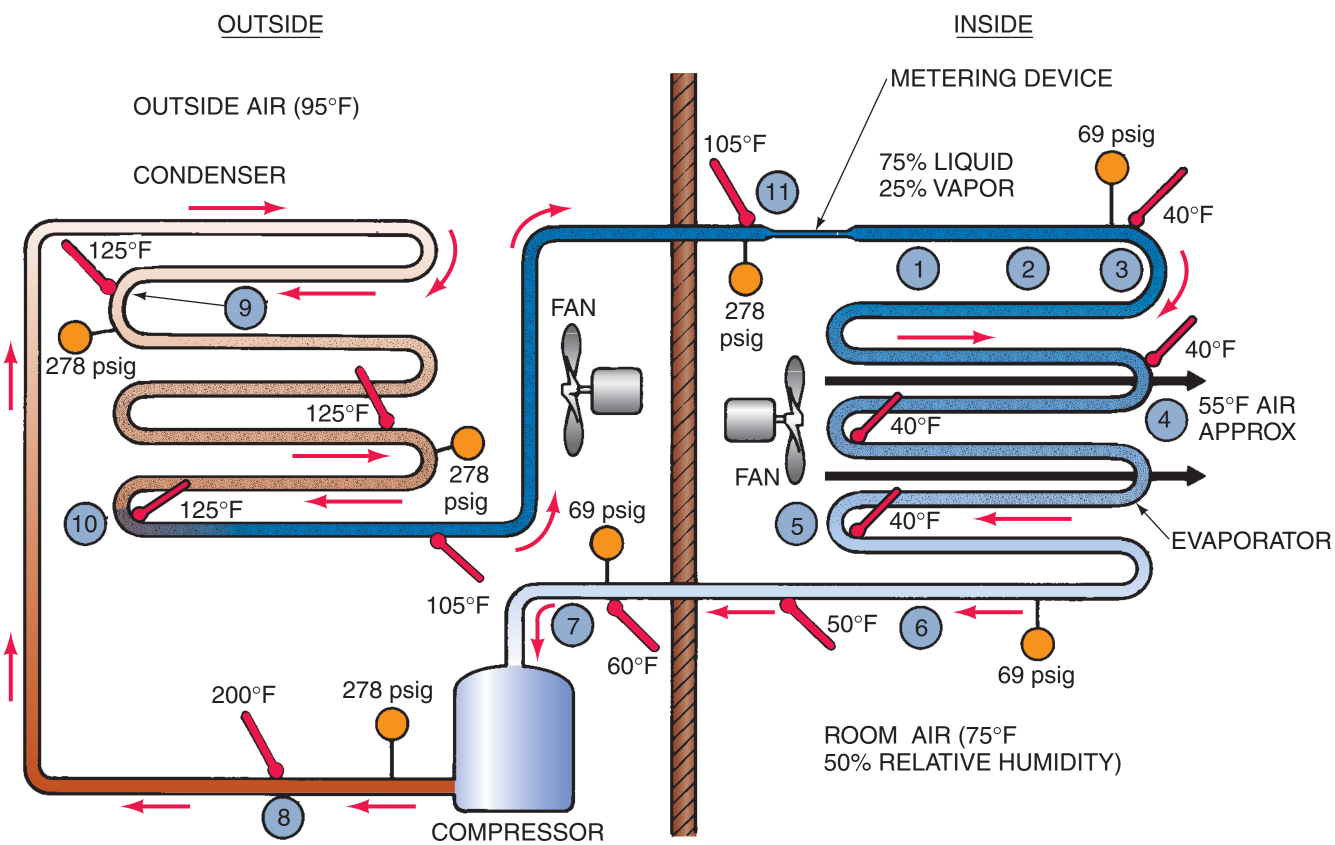


Figure 3–38 A typical R-22 air-conditioning system showing temperatures and airflow. Red indicates warm/hot refrigerant; blue indicates cool/cold refrigerant.

evaporator superheat, while the total superheat that is picked up in the evaporator and the suction line is referred to as system superheat. To calculate the system superheat, we will take the suction line temperature (from item C, above) close to the compressor's inlet instead of at the outlet of the evaporator. In this example, the evaporator superheat is 10°F (50°F − 40°F) and the system superheat is 20°F (60°F − 40°F). System superheat is often referred to as compressor superheat.

7. The vapor is drawn into the compressor by its pumping action, which creates a low-pressure suction. When the vapor left the evaporator, its temperature was about 50°F with 10°F of superheat above the saturated boiling temperature of 40°F. As the vapor moves along toward the compressor, it is contained in the suction line. This line is usually copper and should be insulated to keep it from drawing heat into the system from the surroundings and to prevent it from sweating. However, it still picks up some heat. Because the suction line carries vapor, any heat that it picks up will quickly raise the temperature. Remember that it does not take much sensible heat to raise the temperature of a vapor. Depending on the length of the line and the quality of the insulation, the suction line temperature may be 60°F at the compressor inlet.
8. Highly superheated gas leaves the compressor through the *hot gas line* on the high-pressure side of the system. This line normally is very short because the condenser is usually close to the compressor. On a hot day the hot gas line may be close to 200°F with a pressure of 278 psig. Because the saturated temperature corresponding to 278 psig is 125°F, the hot gas line has about 75°F (200°F − 125°F) of superheat that must be removed before condensing can occur. Because the line is so hot and a vapor is present, the line will give up heat readily to the surroundings. The surrounding air temperature is 95°F.
9. The superheat has been removed and the refrigerant has cooled down to the 125°F condensing temperature. Point 9 is the point in the system where the desuperheating vapor has just cooled to a temperature of 125°F; this is referred to as a 100% saturated vapor point. If any heat is taken away or rejected, liquid will start to form. As more heat is rejected, the remaining saturated vapor will continue to condense to saturated liquid at the condensing temperature of 125°F. Now notice that the coil temperature is corresponding to the high-side pressure of 278 psig and 125°F. The high-pressure reading of 278 psig is due to the refrigerant condensing at 125°F. In fact, 278 psig is the *vapor pressure* that the vapor is exerting on the liquid while it is condensing. Remember, it is vapor pressure that the gage reads. The condensing conditions are arrived at by knowing the efficiency of the condenser. In this example we use a standard condenser, which has a condensing temperature about 30°F higher than the surrounding air used to absorb heat from the condenser. In this example, 95°F outside air is used to absorb the heat—so 95°F + 30°F = 125°F condensing temperature. Some condensers will condense at 25°F above the surrounding air; these are high-efficiency condensers, and the high-pressure side of the system will be operating at a lower pressure. Condensing temperatures and pressures are also dependent on the heat load given to the condenser to reject. The higher the heat load, the higher the condensing temperature and corresponding pressure will be. It can also be concluded that, as the outside temperature rises, the operating pressure on the high side of the system will also rise. For example, if the outside ambient (surrounding) temperature rises to 105°F, the condenser saturation temperature on our sample system would rise to about 135°F.
10. The refrigerant is now 100% liquid at the saturated temperature of 125°F. As the liquid continues along the coil, the air continues to cool the liquid to below the actual condensing temperature. The liquid may go as much as 20°F below the condensing temperature of 125°F before it reaches the metering device. Any liquid at a temperature below the condensing temperature of 125°F is called subcooled liquid. In this example, the liquid is cooled to 105°F before it reaches the metering device. The liquid now has 20°F (125°F − 105°F) of subcooling.
11. The liquid refrigerant reaches the metering device through a pipe, usually copper, from the condenser. This liquid line is often field installed and not insulated. Since the temperature of the liquid line is warmer than the temperature of the surrounding air, keeping the liquid line uninsulated allows some additional heat to be rejected by the refrigerant to the surrounding air. This helps increase the operating efficiency of the system. Since the liquid line may be long, and depending on the distance between the condenser and the metering device, the amount of additional heat being rejected may be significant. Heat given up here is leaving the system, and that is good. The refrigerant entering the metering device may be as much as 20°F cooler than the condensing temperature of 125°F, so the liquid line entering the metering device may be 105°F. The refrigerant entering the metering device is 100% subcooled liquid. In the short distance of the metering device's orifice (a pinhole about the size of a small sewing needle), the subcooled liquid is changed to a mixture of about 75% saturated liquid and 25% saturated vapor. The percent of liquid to vapor leaving the metering device is both system and application dependent. The 25% vapor is known as *flash gas* and is used to cool the remaining 75% of the liquid down to 40°F, the boiling temperature of the evaporator. Flash gas is considered a system loss because it is cooling the liquid temperature down to the 40°F evaporating temperature. This wasted cooling cannot be performed in the evaporator in cooling the inside air and removing humidity. The only way to minimize flash gas is to get the subcooled liquid temperature entering the metering device closer to the evaporating temperature.

The refrigerant has now completed one cycle and is ready to go around again. It should be evident that a refrigerant does the same thing over and over, changing from a liquid to a vapor in the evaporator and back to liquid form in the condenser. The expansion device meters the flow to the evaporator, and the compressor pumps the refrigerant out of the evaporator.

The following statements briefly summarize the refrigeration cycle:

1. **The evaporator absorbs heat into the system.**
2. **The condenser rejects heat from the system.**
3. **The compressor pumps the heat-laden vapor.**
4. **The expansion device meters the flow of refrigerant.**

3.12 REFRIGERANTS

Previously we have used water and R-22 as examples of refrigerants. Although many products have the characteristics of a refrigerant, only a few will be covered here. More detailed information will be provided in Unit 9, "Refrigerant and Oil Chemistry and Management—Recovery, Recycling, Reclaiming, and Retrofitting."

The following four refrigerants either can no longer be manufactured or have phaseout dates in the near future:

R-12—Used primarily in medium- and high-temperature refrigeration applications. Manufacturing and importing banned as of January 1, 1996.

R-22—Used primarily in residential, commercial, and industrial air-conditioning applications and in some commercial and industrial refrigeration. R-22 is subject to phaseout in new equipment in 2010, and total production will be phased out in 2020.

R-500—Used primarily in older air-conditioning applications and some commercial refrigeration. Manufacturing and importing banned as of January 1, 1996.

R-502—Used primarily in low-temperature refrigeration applications. Manufacturing and importing banned as of January 1, 1996. An *azeotropic* refrigerant blend that has no *temperature glide* and behaves like a *pure compound*.

The following are some of the newer, more popular long-term replacement refrigerants:

R-134a—Has properties very similar to R-12. Used primarily in medium- and high-temperature refrigeration applications, refrigerators and freezers, and automotive air conditioning. A replacement for R-12 but not a direct drop-in replacement because retrofitting is required. The ester-based lubricants used with R-134a are not compatible with the oils typically used on R-12 systems.

R-404A—Is replacing R-502 in low- and medium-temperature refrigeration applications. Has slightly higher working pressures than R-502. A *near-azeotropic* refrigerant blend with a small temperature glide.

R-407C—Has similar properties to R-22. Replacing R-22 in residential and commercial air-conditioning applications. Can be used as a retrofit refrigerant for R-22 but has a large temperature glide and fractionation potential. A near-azeotropic refrigerant blend. R-407C, like R-134a, operates with ester-based lubricants that are not compatible with the oils typically used on R-22 systems. R-407C is a great choice when the condensing unit of a system must be replaced, as most of the refrigeration oil is contained in the compressor.

R-410A—Is a near-azeotropic refrigerant blend replacing R-22 in residential and commercial air-conditioning applications. Has much higher operating pressures than R-22. Has special safety concerns. Has a very small temperature glide and is not recommended as a retrofit refrigerant.

SAFETY PRECAUTION: Never add R-410A to a system that was manufactured for use with R-22. R-22 system components are typically not manufactured to accept the higher operating pressures that are present in R-410A systems. For example, the shells of R-410A compressors are manufactured with thicker steel than are the shells of R-22 compressors.

R-507—Is replacing R-502 in low- and medium-temperature refrigeration applications. Has slightly higher pressures and capacity than R-404A. An azeotropic refrigerant blend.

♻ As will be seen later in this unit, the choice of refrigerant is becoming more important because of environmental issues. It has been thought for many years that the common refrigerants were perfectly safe to use. New discoveries have shown that some of the common refrigerants, R-12, R-500, R-502, and R-22, may be causing damage to the ozone layer in the stratosphere, 7 to 30 miles above the earth's surface. Refrigerants are also being blamed for global warming effects that take place in the troposphere, 0 to 7 miles above the earth. ♻

3.13 REFRIGERANTS MUST BE SAFE

A refrigerant must be safe to protect people from sickness or injury, even death, if the refrigerant should escape from its system. For instance, it could be a disaster to use ammonia for the air-conditioning system in a public place even though it is an efficient refrigerant from many standpoints.

Modern refrigerants are nontoxic, and equipment is designed to use a minimum amount of refrigerant to accomplish its job. A household refrigerator or window air conditioner, for example, normally uses less than 2 lb of refrigerant, yet for years almost 1 lb of refrigerant was used as the propellant in a 16-oz aerosol can of hair spray.

SAFETY PRECAUTION: Because refrigerants are heavier than air, proper ventilation is important. For example, if a leak in a large container of refrigerant should occur in a basement, the oxygen could be displaced by the refrigerant and a person could be overcome. Avoid open flame when a refrigerant is present. When refrigeration equipment or cylinders are located in a room with an open gas flame,

such as a pilot light on a gas water heater or furnace, the equipment must be kept leak free. If the refrigerant escapes and gets to the flame, the flame will sometimes burn an off-blue or blue-green. This means the flame is giving off a toxic and corrosive gas that will deteriorate any steel in the vicinity and burn the eyes and nose and severely hamper the breathing of anyone in the room. The refrigerants themselves will not burn.

3.14 REFRIGERANTS MUST BE DETECTABLE

A good refrigerant must be readily detectable. The first leak detection device that can be used for some large leaks is listening for the hiss of the escaping refrigerant. **Figure 3–39(A).** This is not the best way in all cases as some leaks may be so small they may not be heard by the human ear. However, many leaks can be found in this way. There is an ultrasonic leak-detecting device on the market that detects leaks by sound, **Figure 3–39(B).** This leak detector enables the technician to hear the sound of the fluid moving through the piping circuit toward the leak location. The pitch of the emitted sound changes as the sensor is brought closer and closer to the leak.

Soap bubbles are a practical and yet simple leak detector. Commercially prepared products that blow large elastic types of bubbles are used by many service technicians, **Figure 3–39(C).** These are valuable when it is known that a leak is in a certain area. Soap-bubble solution can be applied with a brush to the tubing joint to see exactly where the leak is. When refrigerant lines are below freezing temperature, a small amount of antifreeze can be added to the bubble solution. Leaking refrigerant will cause bubbles, **Figure 3–39(D).** At times a piece of equipment can be submerged in water to watch for bubbles. This is effective when it can be used.

The halide leak detector, **Figure 3–39(E),** is available for use with acetylene or propane gas. It operates on the principle that when the refrigerant is allowed in an open flame in the presence of glowing copper, the flame will change color, **Figure 3–39(F).** The halide leak detector should be used in well-ventilated areas, because the resulting blue or green flame indicates that toxic gas is being produced. Although the amounts produced can be very small, the gas is an irritant—corrosive as well as toxic.

The electronic leak detector in **Figure 3–39(G)** is battery operated, is small enough to be easily carried, and has a flexible probe. Some residential air-conditioning equipment has refrigerant charge specifications that call for half-ounce accuracy. The electronic leak detectors are capable of detecting leak rates down to a quarter of an ounce per year.

Another system uses a high-intensity ultraviolet lamp, **Figure 3–39(H).** An additive is induced into the refrigerant system. The additive will show as a bright yellow-green glow under the ultraviolet lamp at the source of the leak. The area can be wiped clean with a general-purpose cleaner after the leak has been repaired, and the area can be reinspected. The additive can remain in the system. Should a new leak be suspected at a later date it will still show the yellow-green color under the ultraviolet light. This system will detect leaks as small as a quarter of an ounce per year.

3.15 THE BOILING POINT OF THE REFRIGERANT

The boiling point of the refrigerant should be low at atmospheric pressure so that low temperatures may be obtained without going into a vacuum. For example, R-502 can be boiled as low as −50°F before the boiling pressure goes into a vacuum; whereas R-12 can be boiled only down to −21°F before it goes into a vacuum. Water would have to be boiled at 29.67 in. Hg vacuum just to boil at 40°F. NOTE: When using the compound gage below atmospheric pressure, the scale reads in reverse of the inches of mercury absolute scale. It starts at atmospheric pressure and counts down to a perfect vacuum, called inches of mercury vacuum. When possible, design engineers avoid using refrigerants that boil below 0 psig. This is one reason why R-502 was a good choice for a low-temperature system. When a system operates in a vacuum and a leak occurs, the atmosphere is pulled inside the system instead of the refrigerant leaking out of the system.

3.16 PUMPING CHARACTERISTICS

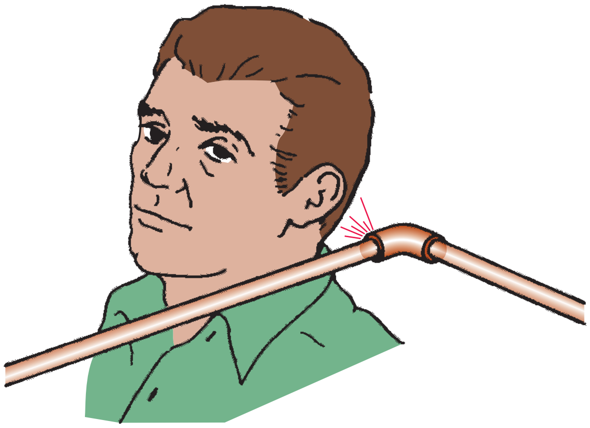
The pumping characteristics have to do with how much refrigerant vapor is pumped per amount of work accomplished. Water was disqualified as a practical refrigerant for small equipment partly for this reason. One pound of water at 40°F has a vapor volume of 2445 ft^3 compared to about 0.6 ft^3 for R-22. As we will see later on, system capacity is directly related to the number of pounds of refrigerant that are circulated through the system per unit of time. This is expressed in units called pounds per minute, or lb/min. Since the vapor volume of 40°F water is so high, the compressor would have to move 2445 ft^3 of vapor to move a single pound. Thus, the compressor would have to be very large for a water system.

Modern refrigerants meet all of these requirements better than any of the older types. **Figure 3–40** presents the temperature/pressure chart for the refrigerants we have discussed.

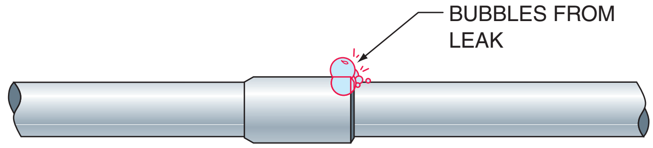
3.17 POPULAR REFRIGERANTS AND THEIR IMPORTANT CHARACTERISTICS

The American National Standards Institute (ANSI) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) are responsible for naming refrigerants and identifying their characteristics. **Figure 3–41** on page 44 is an organized list of some of the more popular refrigerants and their characteristics. For more detailed information on refrigerants, refer to Unit 9, "Refrigerant and Oil Chemistry and Management—Recovery, Recycling, Reclaiming, and Retrofitting."

♻ As mentioned earlier, environmental issues like ozone depletion and global warming have forced many refrigerants to have phaseout dates for manufacturing. However, these



(A)



(D)

(E)

(F)

(B)

(G)

(C)

(H)

Figure 3–39 Common methods used for leak detection. **(A)** Listening for audible leaks. **(B)** Ultrasonic leak detector. **(C)** Soap-bubble solution. **(D)** Soap-bubble solution causes bubbles to form when a leak is present. **(E)** Halide torch. **(F)** The flame on the halide leak detector turns green when a leak is present. **(G)** Electronic leak detector. **(H)** Ultraviolet leak detection equipment. ***(B)** Photo by Bill Johnson.* ***(E)** Courtesy Uniweld Products.* ***(F)** Courtesy Uniweld Products.* ***(G)** Courtesy Ferris State University. Photo by John Tomczyk.* ***(H)** Courtesy Spectronics Corporation*

TEMPERATURE °F	REFRIGERANT 12	22	134a	502	404A	410A	TEMPERATURE °F	REFRIGERANT 12	22	134a	502	404A	410A	TEMPERATURE °F	REFRIGERANT 12	22	134a	502	404A	410A
−60	19.0	12.0		7.2	6.6	0.3	12	15.8	34.7	13.2	43.2	46.2	65.3	42	38.8	71.4	37.0	83.8	89.7	122.9
−55	17.3	9.2		3.8	3.1	2.6	13	16.4	35.7	13.8	44.3	47.4	66.8	43	39.8	73.0	38.0	85.4	91.5	125.2
−50	15.4	6.2		0.2	0.8	5.0	14	17.1	36.7	14.4	45.4	48.6	68.4	44	40.7	74.5	39.0	87.0	93.3	127.6
−45	13.3	2.7		1.9	2.5	7.8	15	17.7	37.7	15.1	46.5	49.8	70.0	45	41.7	76.0	40.1	88.7	95.1	130.0
−40	11.0	0.5	14.7	4.1	4.8	9.8	16	18.4	38.7	15.7	47.7	51.0	71.6	46	42.6	77.6	41.1	90.4	97.0	132.4
−35	8.4	2.6	12.4	6.5	7.4	14.2	17	19.0	39.8	16.4	48.8	52.3	73.2	47	43.6	79.2	42.2	92.1	98.8	134.9
−30	5.5	4.9	9.7	9.2	10.2	17.9	18	19.7	40.8	17.1	50.0	53.5	75.0	48	44.6	80.8	43.3	93.9	100.7	136.4
−25	2.3	7.4	6.8	12.1	13.3	21.9	19	20.4	41.9	17.7	51.2	54.8	76.7	49	45.7	82.4	44.4	95.6	102.6	139.9
−20	0.6	10.1	3.6	15.3	16.7	26.4	20	21.0	43.0	18.4	52.4	56.1	78.4	50	46.7	84.0	45.5	97.4	104.5	142.5
−18	1.3	11.3	2.2	16.7	18.2	28.2	21	21.7	44.1	19.2	53.7	57.4	80.1	55	52.0	92.6	51.3	106.6	114.6	156.0
−16	2.0	12.5	0.7	18.1	19.6	30.2	22	22.4	45.3	19.9	54.9	58.8	81.9	60	57.7	101.6	57.3	116.4	125.2	170.0
−14	2.8	13.8	0.3	19.5	21.1	32.2	23	23.2	46.4	20.6	56.2	60.1	83.7	65	63.8	111.2	64.1	126.7	136.5	185.0
−12	3.6	15.1	1.2	21.0	22.7	34.3	24	23.9	47.6	21.4	57.5	61.5	85.5	70	70.2	121.4	71.2	137.6	148.5	200.8
−10	4.5	16.5	2.0	22.6	24.3	36.4	25	24.6	48.8	22.0	58.8	62.9	87.3	75	77.0	132.2	78.7	149.1	161.1	217.6
−8	5.4	17.9	2.8	24.2	26.0	38.7	26	25.4	49.9	22.9	60.1	64.3	90.2	80	84.2	143.6	86.8	161.2	174.5	235.4
−6	6.3	19.3	3.7	25.8	27.8	40.9	27	26.1	51.2	23.7	61.5	65.8	91.1	85	91.8	155.7	95.3	174.0	188.6	254.2
−4	7.2	20.8	4.6	27.5	30.0	42.3	28	26.9	52.4	24.5	62.8	67.2	93.0	90	99.8	168.4	104.4	187.4	203.5	274.1
−2	8.2	22.4	5.5	29.3	31.4	45.8	29	27.7	53.6	25.3	64.2	68.7	95.0	95	108.2	181.8	114.0	201.4	219.2	295.0
0	9.2	24.0	6.5	31.1	33.3	48.3	30	28.4	54.9	26.1	65.6	70.2	97.0	100	117.2	195.9	124.2	216.2	235.7	317.1
1	9.7	24.8	7.0	32.0	34.3	49.6	31	29.2	56.2	26.9	67.0	71.7	99.0	105	126.6	210.8	135.0	231.7	253.1	340.3
2	10.2	25.6	7.5	32.9	35.3	50.9	32	30.1	57.5	27.8	68.4	73.2	101.0	110	136.4	226.4	146.4	247.9	271.4	364.8
3	10.7	26.4	8.0	33.9	36.4	52.3	33	30.9	58.8	28.7	69.9	74.8	103.1	115	146.8	242.7	158.5	264.9	290.6	390.5
4	11.2	27.3	8.6	34.9	37.4	53.6	34	31.7	60.1	29.5	71.3	76.4	105.1	120	157.6	259.9	171.2	282.7	310.7	417.4
5	11.8	28.2	9.1	35.8	38.4	55.0	35	32.6	61.5	30.4	72.8	78.0	107.3	125	169.1	277.9	184.6	301.4	331.8	445.8
6	12.3	29.1	9.7	36.8	39.5	56.4	36	33.4	62.8	31.3	74.3	79.6	108.4	130	181.0	296.8	198.7	320.8	354.0	475.4
7	12.9	30.0	10.2	37.9	40.6	57.8	37	34.3	64.2	32.2	75.8	81.2	111.6	135	193.5	316.6	213.5	341.2	377.1	506.5
8	13.5	30.9	10.8	38.9	41.7	59.3	38	35.2	65.6	33.2	77.4	82.9	113.8	140	206.6	337.2	229.1	362.6	401.4	539.1
9	14.0	31.8	11.4	39.9	42.8	60.7	39	36.1	67.1	34.1	79.0	84.6	116.0	145	220.3	358.9	245.5	385.9	426.8	573.2
10	14.6	32.8	11.9	41.0	43.9	62.2	40	37.0	68.5	35.1	80.5	86.3	118.3	150	234.6	381.5	262.7	408.4	453.3	608.9
11	15.2	33.7	12.5	42.1	45.0	63.7	41	37.9	70.0	36.0	82.1	88.0	120.5	155	249.5	405.1	280.7	432.9	479.8	616.2

VACUUM (in. Hg) – RED FIGURES
GAGE PRESSURE (psig) – BOLD FIGURES

Figure 3–40 This chart shows the temperature/pressure relationship in in. Hg vacuum, or psig. Pressures for R-404A and R-410A are an average liquid and vapor pressure.

refrigerants can still be used if recovered or recycled, or if they are in an operating refrigeration or air-conditioning system. Environmental issues and phaseout dates have made many refrigerants very expensive due to the heavy taxes imposed. Alternative (environmentally friendly) refrigerants have entered the market because of these issues. It is now illegal to intentionally vent to the atmosphere any refrigerant. Stiff fines of up to $32,500 and/or imprisonment can follow. Because of this, mandatory technician certification programs have educated HVACR personnel on environmental issues, alternative refrigerants, and legislation issues.

3.18 REFRIGERANT CYLINDER COLOR CODES

Each type of refrigerant is contained in a cylinder or drum that has a designated color. Following are the colors for some of the most frequently used refrigerants.

R-407B	Cream	R-114	Dark blue
R-407C	Chocolate	R-500	Yellow
R-410A	Rose	R-502	Orchid
R-11	Orange	R-717	Silver
R-12	White	R-409A	Tan
R-22	Green	R-123	Light gray
R-113	Purple	R-401A	Coral red
R-134a	Light blue	R-401B	Mustard yellow
R-401C	Aqua	R-404A	Orange
R-402A	Light brown	R-406A	Light gray-green
R-402B	Green-brown	R-407A	Bright green

Some equipment manufacturers color code their compressors to indicate the type of refrigerant used in the system. **Figure 3–42** shows refrigerant containers for some newer refrigerants.

3.19 RECOVERY, RECYCLE, OR RECLAIM OF REFRIGERANTS

It is mandatory for technicians to recover and sometimes recycle refrigerants during installation and servicing operations to help reduce emissions of chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs) to the atmosphere. Examples of recovery equipment are shown in **Figure 3–43.** Many larger systems can be fitted with receivers or dump tanks into which the refrigerant can be pumped and stored while the system is serviced. However, in smaller capacity systems it is not often feasible to provide these components. Recovery units or other storage devices may be necessary. Most recovery and/or recycle units that have been developed to date vary in their technology and capabilities so manufacturers' instructions must be followed carefully when using this equipment. Unit 9 includes a detailed description of the recovery, recycle, and reclaim of refrigerants.

ANSI/ASHRAE designation	Safety* classification	Empirical formula	Molecular formula	Components/weight percentages Chemical name	Cylinder color
R-11	A1	CFC	CCl_3F	Trichlorofluoromethane	Orange
R-12	A1	CFC	CCl_2F_2	Dichlorodifluoromethane	White
R-13	A1	CFC	$CClF_3$	Chlorotrifluoromethane	Light Blue
R-14	A1	PFC	CF_4	Tetrafluoromethane	Mustard
R-22	A1	HCFC	$CHClF_2$	Chlorodifluoromethane	Light Green
R-23	A1	HFC	CHF_3	Trifluoromethane	Light Gray-Blue
R-32	A2	HFC	CH_2F_2	Difluoromethane	White/Red Stripe
R-113	A1	CFC	$CCl_2F\text{-}CClF_2$	1,1, 2-Trichloro-1, 2, 2-trifluoroethane	Dark Purple (Violet)
R-114	A1	CFC	$CClF_2\text{-}CClF_2$	1, 2-Dichloro-1,1, 2, 2-tetrafluoroethane	Dark Blue (Navy)
R-115	A1	CFC	$CClF_2\text{-}CF_3$	Chloropentafluoroethane	White/Red Stripe
R-116	A1	PFC	$CF_3\text{-}CF_3$	Hexafluoroethane	Dark Gray (Battleship)
R-123	B1	HCFC	$CHCl_2\text{-}CF_3$	2, 2-Dichloro-1,1,1-trifluoroethane	Light Gray-Blue
R-124	A1	HCFC	$CHClF\text{-}CF_3$	2-Chloro-1,1,1, 2-tetrafluoroethane	Dark Green
R-125	A1	HFC	$CHF_2\text{-}CF_3$	Pentafluoroethane	Medium Brown (Tan)
R-134a	A1	HFC	$CH_2F\text{-}CF_3$	1,1,1, 2-Tetrafluoroethane	Light Sky Blue
R-143a	A2	HFC	$CH_3\text{-}CF_3$	1,1,1-Trifluoroethane	White/Red Stripe
R-152a	A2	HFC	$CH_3\text{-}CHF_2$	1,1-Difluoroethane	White/Red Stripe
R-290	A3	HC	$CH_3\text{-}CH_2\text{-}CH_3$	Propane	White
R-500	A1	CFC	$CCl_2F_2/CH_3\text{-}CHF_2$	R-12/R-152a 73.8/26.2	Yellow
R-502	A1	CFC	$CHClF_2/CClF_2\text{-}CF_3$	R-22/R-115 48.8/51.2	Light Purple (Lavender)
R-503	A1	CFC	$CHF_3/CClF_3$	R-23/R-13 40.1/59.9	Blue-Green (Aqua)
R-507	A1/A1	HFC	$CHF_2\text{-}CF_3/CH_3\text{-}CF_3$	R-125/R-143a 50/50	Blue-Green (Teal)
R-717	B2		NH_3	Ammonia	Silver
R-401A	A1/A1	HCFC	$CHClF_2/CH_3\text{-}CHF_2/CHClF\text{-}CF_3$	R-22/R-152a/R-124 53/13/34	Coral Red
R-401B	A1/A1	HCFC	$CHClF_2/CH_3\text{-}CHF_2/CHClF\text{-}CF_3$	R-22/R-152a/R-124 61/11/28	Yellow-Brown (Mustard)
R-401C	A1/A1	HCFC	$CHClF_2/CH_3\text{-}CHF_2/CHClF\text{-}CF_3$	R-22/R-152a/R-124 33/15/52	Blue-Green (Aqua)
R-402A	A1/A1	HCFC	$CHF_2\text{-}CF_3/CH_3\text{-}CH_2\text{-}CH_3/CHClF_2$	R-125/R-290/R-22 60/02/38	Light Brown (Sand)
R-402B	A1/A1	HCFC	$CHF_2\text{-}CF_3/CH_3\text{-}CH_2\text{-}CH_3/CHClF_2$	R-125/R-290/R-22 38/02/60	Green-Brown (Olive)
R-403A	A1/A1	HCFC	$CH_3\text{-}CH_2\text{-}CH_3/CHClF_2/CF_3\text{-}CF_2\text{-}CF_3$	R-290/R-22/R-218 05/75/20	Light Purple
R-404A	A1/A1	HFC	$CHF_2\text{-}CF_3/CH_3\text{-}CF_3/CH_2F\text{-}CF_3$	R-125/R-143a/R-134a 44/52/04	Orange
R-406A	A1/A2	HCFC	$CHClF_2/CH(CH_3)_3/CH_3\text{-}CClF_2$	R-22/R-600a/R-142b 55/04/41	Light Gray-Green
R-407A	A1/A1	HFC	$CH_2F_2/CHF_2\text{-}CF_3/CH_2F\text{-}CF_3$	R-32/R-125/R-134a 20/40/40	Bright Green
R-407B	A1/A1	HFC	$CH_2F_2/CHF_2\text{-}CF_3/CH_2F\text{-}CF_3$	R-32/R-125/R-134a 10/70/20	Cream
R-407C	A1/A1	HFC	$CH_2F_2/CHF_2\text{-}CF_3/CH_2F\text{-}CF_3$	R-32/R-125/R-134a 23/25/52	Medium Brown
R-408A	A1/A1	HCFC	$CHF_2\text{-}CF_3/CH_3\text{-}CF_3/CHClF_2$	R-125/R-143a/R-22 07/46/47	Medium Purple
R-409A	A1/A1	HCFC	$CHClF_2/CHClF\text{-}CF_3/CH_3\text{-}CClF_2$	R-22/R-124/R-142b 60/25/15	Mustard Brown (Tan)
R-410A	A1/A1	HFC	$CH_2F_2/CHF_2\text{-}CF_3$	R-32/R-125 50/50	Rose

Figure 3–41 A list of refrigerants and some of their characteristics. *NOTE: Safety classifications are covered in Unit 4, "General Safety Practices."

Figure 3–42 Color-coded refrigerant cylinders and drums for some of the newer refrigerants. *Courtesy National Refrigerants, Inc.*

Figure 3–43 Recovery units. *Photo by Eugene Silberstein*

3.20 PLOTTING THE REFRIGERANT CYCLE

A graphic picture of the refrigerant cycle may be plotted on a pressure/enthalpy diagram. This diagram plots pressure on the left-hand side of the diagram and enthalpy on the bottom of the diagram, **Figure 3–44.** *Enthalpy* describes how much heat a substance contains with respect to an accepted reference point. Quite often, people refer to enthalpy as total heat, but this is not absolutely accurate because it refers to the heat content above the selected reference point. Refer to **Figure 1–15,** the heat/temperature graph for water. We used 0°F as the starting point of heat for water, knowing that you can really remove more heat from the water (ice) and lower the temperature below 0°F. We described the process as the amount of heat added starting at 0°F. This heat is called enthalpy. The pressure/enthalpy diagram is a similar diagram, is available for all refrigerants, and is sometimes referred to as a p-e (pressure/enthalpy) or p-h (pressure/heat) chart. Since different refrigerants have different characteristics, properties, and temperature/pressure relationships, the pressure/enthalpy chart for each refrigerant is different. The pressure/enthalpy chart is used to plot the complete refrigeration cycle as a continuous loop.

The selected reference point for measuring the heat content in a refrigerant is −40°F. On the pressure/enthalpy chart in **Figure 3–45,** it can be seen that the enthalpy or heat content, in Btu/lb (along the bottom of the chart), has a value of 0 Btu/lb when the refrigerant is a saturated liquid at −40°F. The heat content for temperature readings below −40°F saturated liquid are indicated as being negative. As we move from left to right on the chart, the heat content per pound of refrigerant increases. As we move from right to left, the heat content per pound of refrigerant decreases.

As you inspect the pressure/enthalpy chart in **Figure 3–44,** you will notice that there is a horseshoe-shaped curve toward the center of the chart. This curve is called the saturation curve and contains the same information that is contained on the temperature/pressure chart that was discussed earlier.

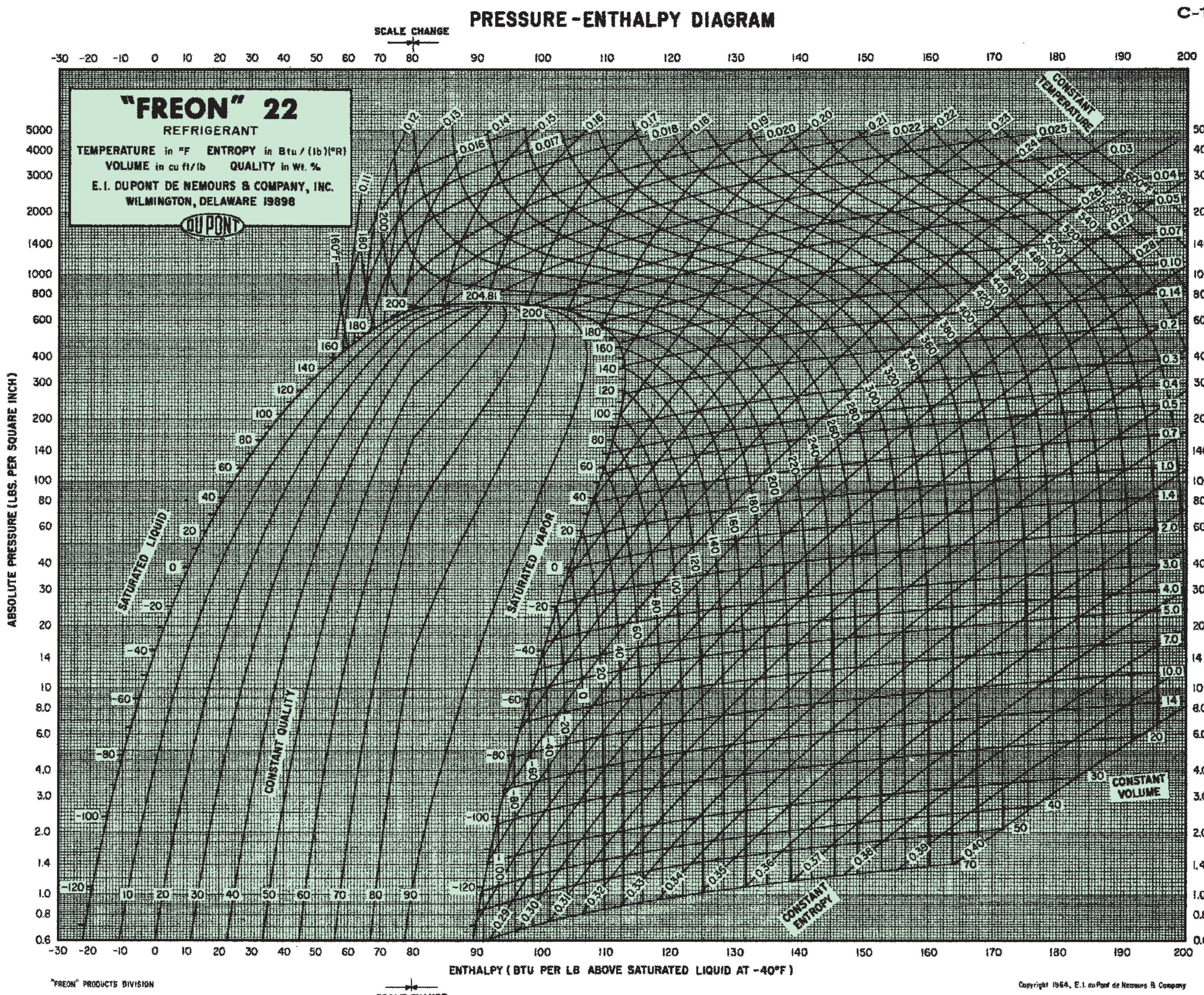


Figure 3–44 The pressure/enthalpy chart relates system operating pressure and temperatures to the heat content of the refrigerant in Btu/lb. *Courtesy E. I. DuPont*

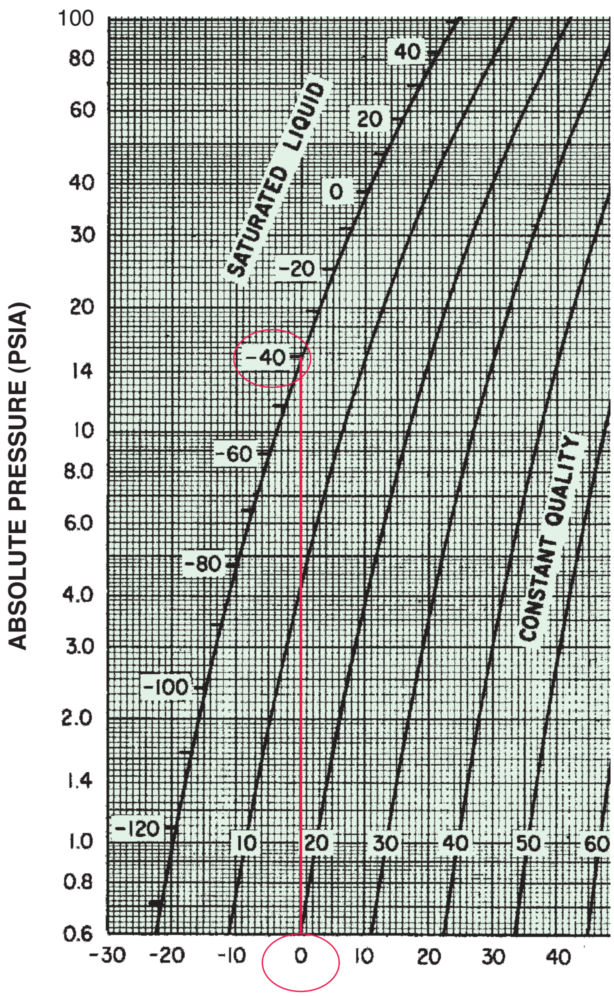


Figure 3–45 The reference point used for measuring heat content is saturated liquid at −40°F. *Courtesy E. I. DuPont*

The only difference is that the pressures on the pressure/enthalpy chart are expressed in absolute pressures, psia, instead of gage pressures, psig.

Any time a plot falls on, or under, this curve, the refrigerant is saturated and will have a corresponding temperature and pressure relationship. Two saturation curves exist; the one on the left is the saturated liquid curve. If heat is added, the refrigerant will start changing state to a vapor. If heat is removed, the liquid will be subcooled. The right-hand curve is the saturated vapor curve. If heat is added, the vapor will superheat. If heat is removed, the vapor will start changing state to a liquid. Notice that the saturated liquid and vapor curves touch at the top. This is called the critical temperature, or pressure. Above this point, the refrigerant will not condense. It is a vapor regardless of how much pressure is applied.

The area between the saturated liquid and saturated vapor curve, inside the horseshoe-shaped curve, is where the change of state occurs. Any time a plot falls between the saturation curves, the refrigerant is in the partial liquid, partial vapor state. The slanted, near-vertical lines between the saturated liquid and saturated vapor lines are the constant quality lines and describe the percentage of vapor to liquid in the mixture between the saturation points. There are nine of these lines under the saturation curve and each of these lines represents 10%. The saturated liquid line on the left side of the curve represents 0% vapor and 100% liquid, while the saturated vapor line on the right side of the saturation curve represents 100% vapor and 0% liquid. The nine constant quality lines that are located under the saturation curve are labeled, from left to right, 10 through 90. These numbers represent the percentage of quality. Percentage of *quality* means percentage of vapor. This means that if a point falls on the 20% constant quality line, it would be 20% vapor and 80% liquid. If the plot is closer to the saturated liquid curve, there is more liquid than vapor. If the plot is closer to the saturated vapor curve, there is more vapor than liquid. For example, let's find a point on the chart at 40°F (on the saturated liquid curve) and 30 Btu/lb (along the bottom), **Figure 3–46.** This point is inside the horseshoe-shaped curve, and the refrigerant is 90% liquid and 10% vapor. **Figure 3–47** summarizes in skeletal form the important regions, points, and lines of the pressure/enthalpy diagram. For practical reasons, we will use only a few of these skeletal forms for illustrating the functions of the refrigeration cycle.

A refrigeration cycle is plotted in **Figure 3–48** on page 49. The system to be plotted is an air-conditioning system using R-22. The system is operating at 130°F condensing temperature (296.8 psig or 311.5 psia discharge pressure) and an evaporating temperature of 40°F (68.5 psig or 83.2 psia suction pressure). The cycle plotted has no subcooling, and 10°F of superheat as the refrigerant leaves the evaporator with another 10°F of superheat absorbed by the refrigerant in the suction line as it returns to the compressor. The compressor is an air-cooled compressor, and the suction gas enters the suction valve adjacent to the cylinders. Assume that the hot gas line is very short and its heat of rejection is negligible. The following five steps summarize the basic refrigeration cycle (refer to **Figure 3–48**):

1. Refrigerant R-22 enters the expansion device as a saturated liquid at 311.5 psia (296 psig) and 130°F, point A. The heat content is 49 Btu/lb entering the expansion valve and 49 Btu/lb leaving the expansion valve. It can be seen in **Figure 3–48** that the metering device is represented by a vertical line. It can therefore be concluded that, even though the temperature and pressure of the refrigerant drops as it flows through the metering device, the heat content of the refrigerant remains the same. It is important that heat content (Btu/lb) is not confused with temperature. Note that the temperature of the liquid refrigerant before the valve is 130°F, and the temperature leaving the valve is 40°F. The temperature drop can be accounted for by observing that we have 100% liquid entering the valve and about 70% liquid leaving the valve. About 30% of the liquid has changed to a vapor (called flash gas). During the process of evaporating, heat is absorbed from the remaining liquid, lowering its temperature to 40°F. Remember, this flash gas does not contribute to the net refrigeration effect. The *net refrigeration effect (NRE)* is expressed in Btu/lb and is the quantity of

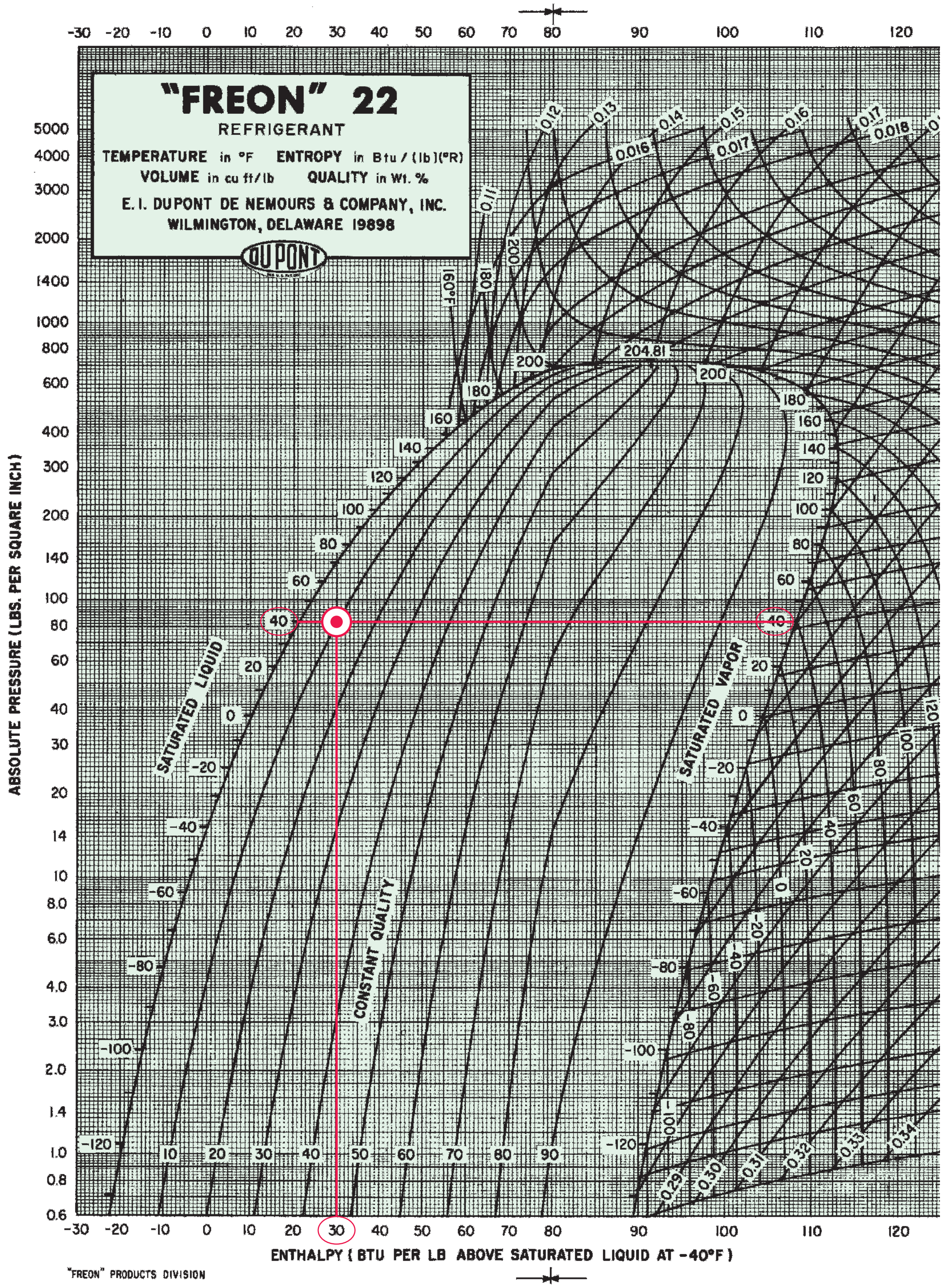


Figure 3–46 The quality of saturated R-22 at 40°F and with a heat content of 30 Btu/lb is 10% vapor and 90% liquid. *Courtesy E. I. DuPont*

heat that each pound of refrigerant absorbs from the refrigerated space to produce useful cooling.

Flash gas occurs because the refrigerant entering the evaporator from the metering device (130°F) must be cooled to the evaporating temperature (40°F) before the remaining liquid can evaporate in the evaporator and produce useful cooling as part of the net refrigeration effect. The heat needed to flash the liquid came from the liquid itself and not from the conditioned space. No enthalpy is gained or lost in this process, which further explains why the expansion line from point A to point B happened at a constant enthalpy. This expansion process is called *adiabatic expansion* because it happened at a constant enthalpy. Adiabatic processes, by definition, result in temperature and pressure changes with no change in heat content.

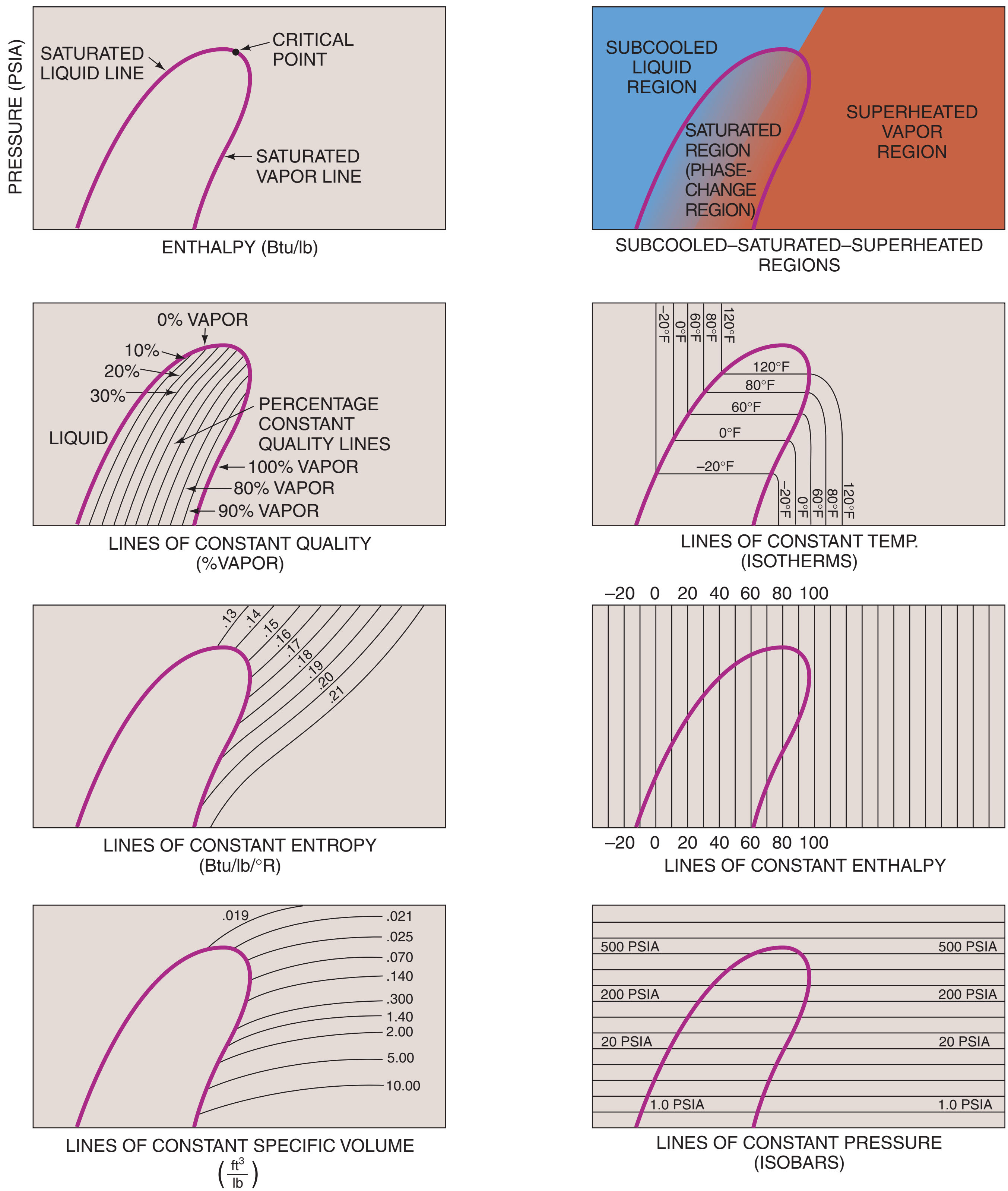


Figure 3–47 Skeletal pressure/enthalpy diagrams.

2. Usable refrigeration starts at point B where the refrigerant has a heat content of 49 Btu/lb. As heat is added to the refrigerant in the evaporator, the refrigerant gradually changes state to a vapor. Notice that, as we move toward the right from point B in a horizontal line, the pressure remains unchanged but the heat content increases. The source of this increase in enthalpy is the heat content in the air being cooled by the evaporator. All liquid has changed to a vapor when it reaches the saturated vapor curve, and a small

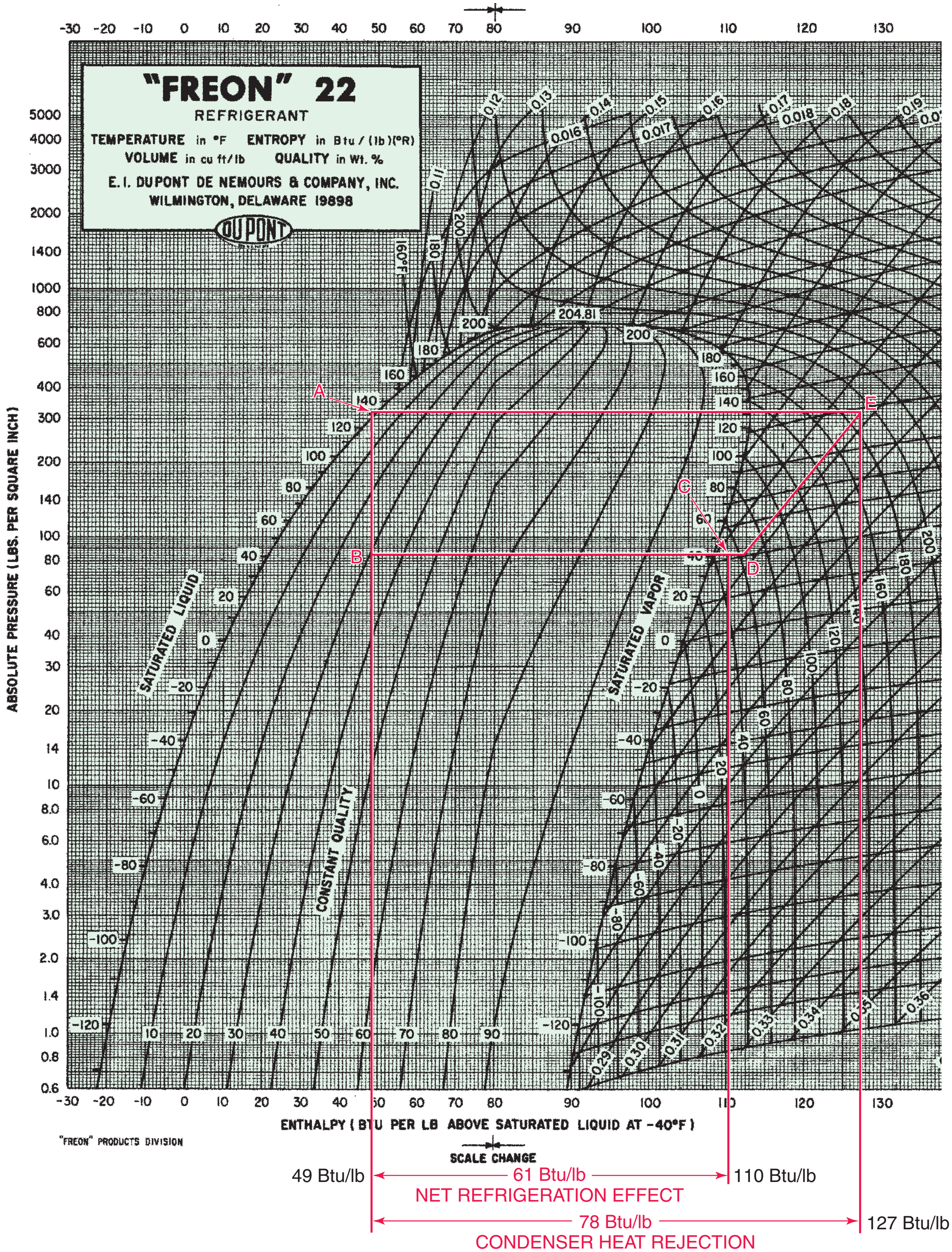


Figure 3–48 A refrigeration cycle plotted on a pressure/enthalpy chart. *Courtesy E. I. DuPont*

amount of heat is added to the refrigerant in the form of superheat (10°F). When the refrigerant leaves the evaporator at point C, it contains about 110 Btu/lb. This is a net refrigeration effect of 61 Btu/lb (110 Btu/lb − 49 Btu/lb = 61 Btu/lb) of refrigerant circulated. The net refrigeration effect, NRE, is the same as usable refrigeration, the heat actually extracted from the conditioned space. About 10 more Btu/lb are

absorbed into the suction line before reaching the compressor inlet at point D. This is not usable refrigeration because the heat does not come from the conditioned space, but it is heat that must be pumped by the compressor and rejected by the condenser.

3. The refrigerant enters the compressor at point D and leaves the compressor at point E. No heat has been added in the compressor except heat of compression, because the compressor is air cooled. Some of the heat of compression will conduct to the head of the compressor and be rejected to the surroundings. The refrigerant enters the compressor cylinder from the suction line. (A fully hermetic compressor with a suction-cooled motor would not plot out just like this. We have no way of knowing how much heat is added by the motor so we do not know what the temperature of the suction gas entering the compressor cylinder would be for a suction-cooled motor. Manufacturers obtain their own figures for this using internal thermometers during testing.) Notice that the line that represents the compressor is sloped up and to the right. This indicates that both the heat content and pressure of the refrigerant are increasing.

   The line that represents the compressor is drawn parallel to another set of lines on the chart that are referred to as lines of constant *entropy*, **Figure 3–47.** Entropy, in our case, represents the compression process and the relationship among the system characteristics of heat content, absolute pressure, and absolute temperature. These lines of constant entropy indicate that, during the compression process, the changes in pressure and temperature are predictable. The units of constant entropy are Btu/lb/°R, where °R is an absolute temperature (as mentioned in Unit 1).

4. The refrigerant leaves the compressor at point E and contains about 127 Btu/lb. At point E, the refrigerant is now at the outlet of the compressor and traveling in the discharge line toward the condenser. This condenser must reject 78 Btu/lb (127 Btu/lb − 49 Btu/lb = 78 Btu/lb), called the heat of rejection. Remember that the condenser must reject all of the heat that is absorbed in the evaporator and suction line as well as the heat generated and concentrated in the compressor during the compression process. Therefore, the heat of rejection is also referred to as the total heat of rejection, THOR, because the condenser must reject all of the heat introduced to the system.

   At point E we can also determine the temperature at the outlet of the compressor. We can do this by looking at the position of the point with respect to the lines of constant temperature, which are the downward-sloped, curved lines on the right-hand side of the saturation curve, **Figure 3–49.** The temperature of the discharge gas is about 190°F (see the constant temperature lines for temperature of superheated gas). When the hot gas leaves the compressor it contains the maximum amount of heat that must be rejected by the condenser.

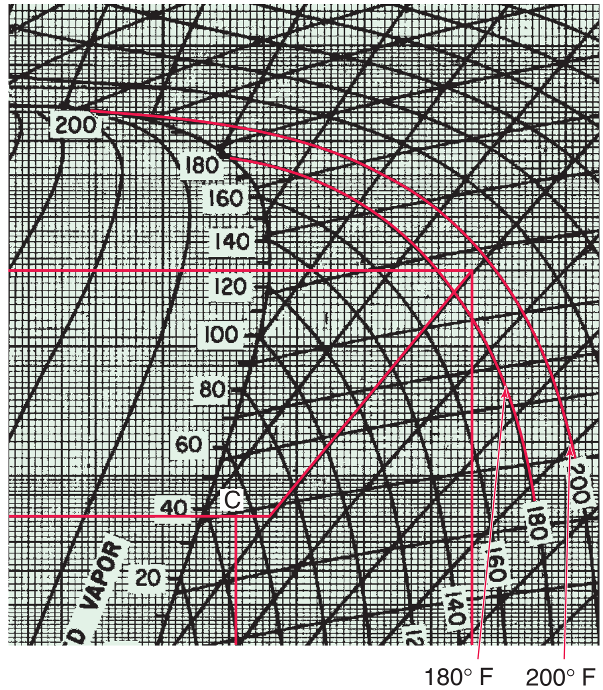


Figure 3–49 The compressor discharge temperature can be found by locating point E and its relation to the constant temperature lines. The compressor discharge temperature shown here is 190°F. *Courtesy E. I. DuPont*

5. The refrigerant enters the condenser at point E as a highly superheated gas. The refrigerant condensing temperature is 130°F and the hot gas leaving the compressor is 190°F, so it contains 60°F (190°F − 130°F = 60°F) of superheat. The condenser will first remove the superheat down to the condensing temperature, which falls on the saturated vapor line. (This process is, once again, referred to as desuperheating.) Then, the condenser will condense the refrigerant to a liquid at 130°F for reentering the expansion device at point A, the saturated liquid line, for another trip around the cycle.

The refrigerant cycle in the previous example can be improved by removing some heat from the condensed liquid by subcooling it. This can be seen in **Figure 3–50,** a scaled-up diagram. The same conditions are used in this figure as in **Figure 3–48,** except the liquid is subcooled 20°F (from 130°F condensing temperature to 110°F liquid). The system then has a net refrigeration effect of 68 Btu/lb instead of 61 Btu/lb. This is an increase in capacity of about 11%. Notice the liquid leaving the expansion valve is only about 23% vapor instead of the 30% vapor in the first example. Also notice that the heat content at the outlet of the metering device is 42 Btu/lb, so the NRE of 68 Btu/lb was determined by subtracting the heat content of 42 Btu/lb at the inlet of the evaporator from the heat content of 110 Btu/lb at the outlet of the evaporator (110 Btu/lb − 42 Btu/lb = 68 Btu/lb). This is where the capacity is gained. Less capacity is lost to flash gas, because the subcooled liquid temperature at 110°F is now a bit closer to the evaporator temperature of 40°F.

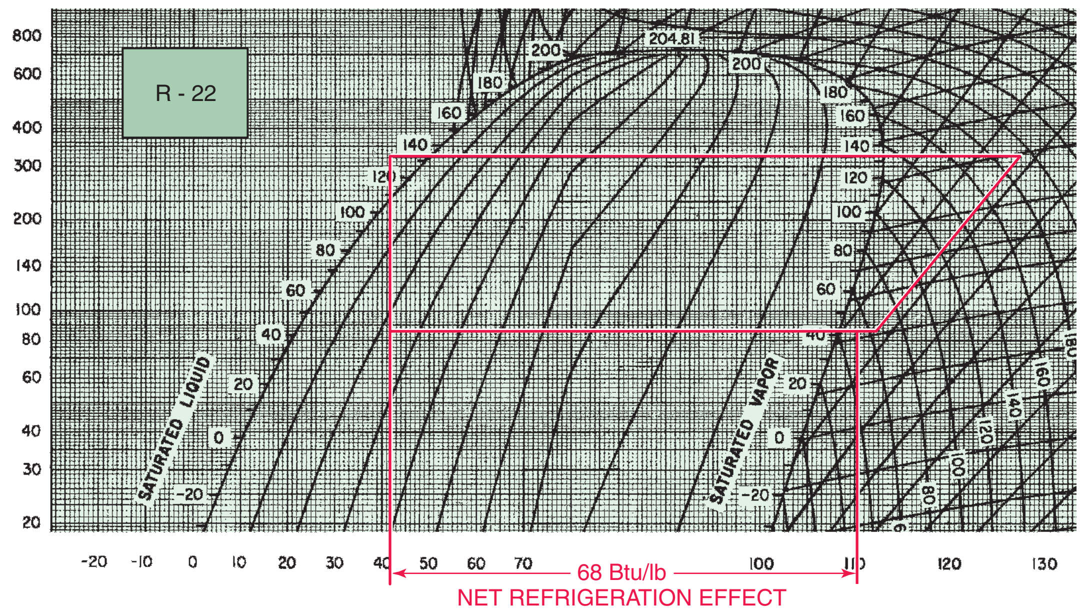


Figure 3–50 Adding subcooling increases the net refrigeration effect of the system. *Courtesy E. I. DuPont*

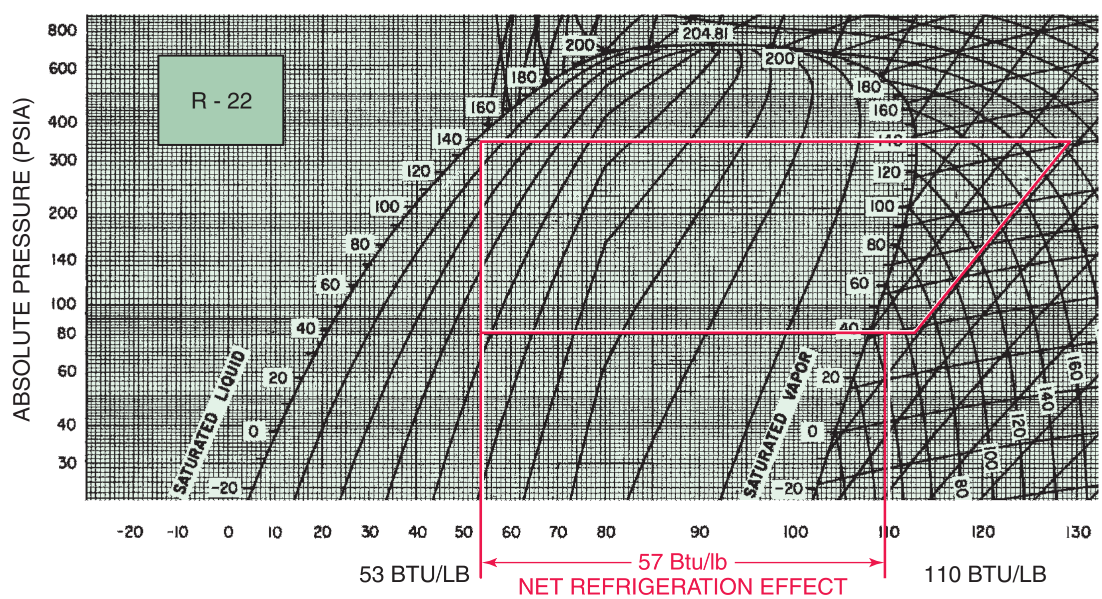


Figure 3–51 A rise in system head pressure will result in a reduction of system capacity. *Courtesy E. I. DuPont*

Other conditions may be plotted on the pressure/enthalpy diagram. For example, suppose the head pressure is raised due to a dirty condenser, **Figure 3–51.** Using the first example, **Figure 3–48,** and raising the condensing temperature to 140°F (337.2 psig or 351.9 psia), we see the percentage of liquid leaving the expansion valve to be about 64% (36% flash gas) with a heat content of 53 Btu/lb. Using the same heat content leaving the evaporator, 110 Btu/lb, we have a net refrigeration effect of 57 Btu/lb. This is a net refrigeration effect reduction of about 7% from the original example, which contained 49 Btu/lb at the same point. This shows the importance of keeping condensers clean.

Figure 3–52 shows how increased superheat affects the first system in **Figure 3–48.** The suction line has not been insulated and absorbs heat. The suction gas may leave the evaporator at 50°F and rise to 75°F before entering the compressor. Notice the high discharge temperature (about 200°F). This is approaching the temperature that will cause oil to break down and form acids in the system. Most compressors must not exceed 250°F. The compressor must pump more

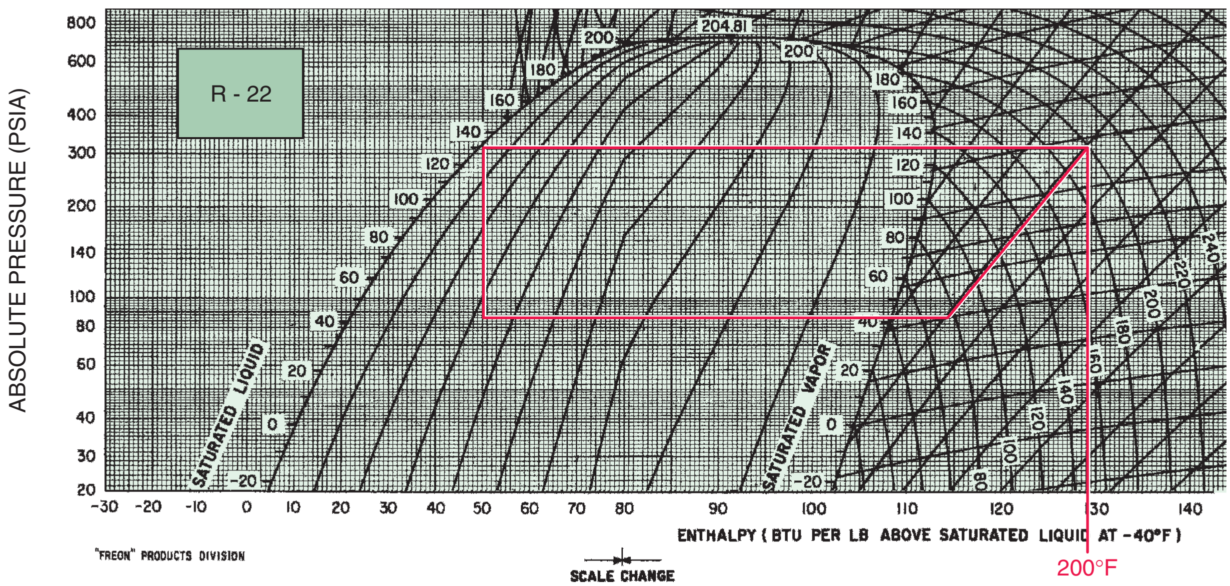


Figure 3–52 An increase in superheat results in an increase in compressor discharge temperature. *Courtesy E. I. DuPont*

refrigerant to accomplish the same refrigeration effect, and the condenser must reject more heat.

R-12 has been the most popular refrigerant for medium-temperature applications for many years. Environmental issues have caused the manufacturers to explore some different refrigerants for the replacement of R-12, namely, R-134a, R-22, and the newer refrigerant blends. R-134a has a zero ozone depletion potential but has oil compatibility problems and cannot be easily retrofitted into existing R-12 systems. R-134a also suffers in capacity when used in low-temperature applications. Environmental issues will be covered in Unit 9.

The following sequence shows how R-12 performs in a typical medium-temperature application. We will use an evaporator temperature of 20°F and a condensing temperature of 115°F. This lower condensing temperature is common for medium- and low-temperature applications. Follow the description in the illustration in **Figure 3–53.** The pressure/enthalpy explanation appears in **Figure 3–54.**

1. Liquid enters the expansion valve at point A at 100°F. Note that the liquid is subcooled 15°F to 100°F, **Figure 3–54.**
2. Partial liquid and partial vapor leave the expansion valve at point B (16% vapor and 84% liquid). The heat content per pound is 31 Btu/lb.
3. Vapor refrigerant leaves the evaporator at point C with 10° of superheat and a heat content of 82 Btu/lb. Note that the net refrigeration effect is 51 Btu/lb (82 − 31 = 51).
4. The refrigerant enters the compressor at point D at a temperature of 50°F. The refrigerant has a total of 30° of superheat considering what was picked up in the evaporator and the suction line. The heat content at the inlet of the compressor is 84 Btu/lb. This means that, in the suction line, each pound of refrigerant picks up 2 Btu/lb (84 Btu/lb − 82 Btu/lb) that must later be rejected by the condenser.
5. The refrigerant is compressed along the line between point D and E, where it leaves the compressor at a temperature of 160°F. Note the lower discharge temperature of 160°F. This is because we are operating at a lower head (condensing) pressure, which causes the heat of compression to be lowered. This is accomplished with a larger condenser.
6. The refrigerant is then desuperheated from point E to the saturated vapor line. Since the refrigerant is discharged from the compressor at a temperature of 160°F and will begin to condense at a temperature of 115°F, the refrigerant must be desuperheated 45°F (160°F − 115°F).
7. The refrigerant is now gradually condensed from the saturated vapor line to the saturated liquid line at 115°F. Notice that, as we follow the line from point E (the compressor outlet) to point A (the inlet of the metering device), we are moving from right to left. Since we are moving in that direction, the heat content of the refrigerant is decreasing. This is consistent with the operation of the condenser, which is the system component that is responsible for rejecting system heat.
8. The liquid is now subcooled from the saturated liquid line to point A. The process then repeats itself.

Following is an example of the same system using R-22, for medium-temperature application. Follow the description in **Figure 3–55** and compare with the previous example.

1. Refrigerant enters the expansion valve at point A at 100°F, subcooled 15°F from the condensing temperature of 115°F, just like the example for R-12.
2. The refrigerant leaves the expansion valve at point B at 28% vapor and 72% liquid with a heat content of 38 Btu/lb. It then travels through the evaporator.
3. The refrigerant leaves the evaporator at point C in the vapor state with 10° of superheat, a heat content of 108 Btu/lb, and a net refrigeration effect of 70 Btu/lb.

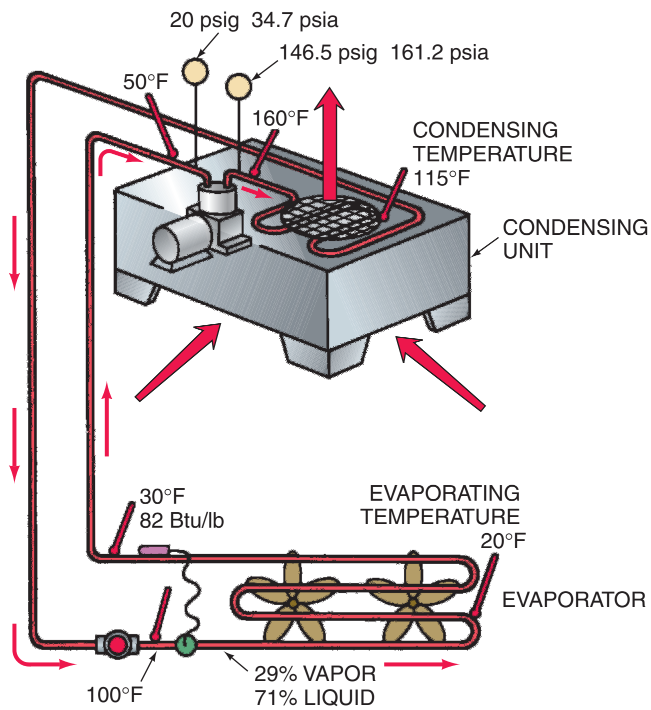


Figure 3–53 A medium-temperature refrigeration system showing operating temperatures and pressures.

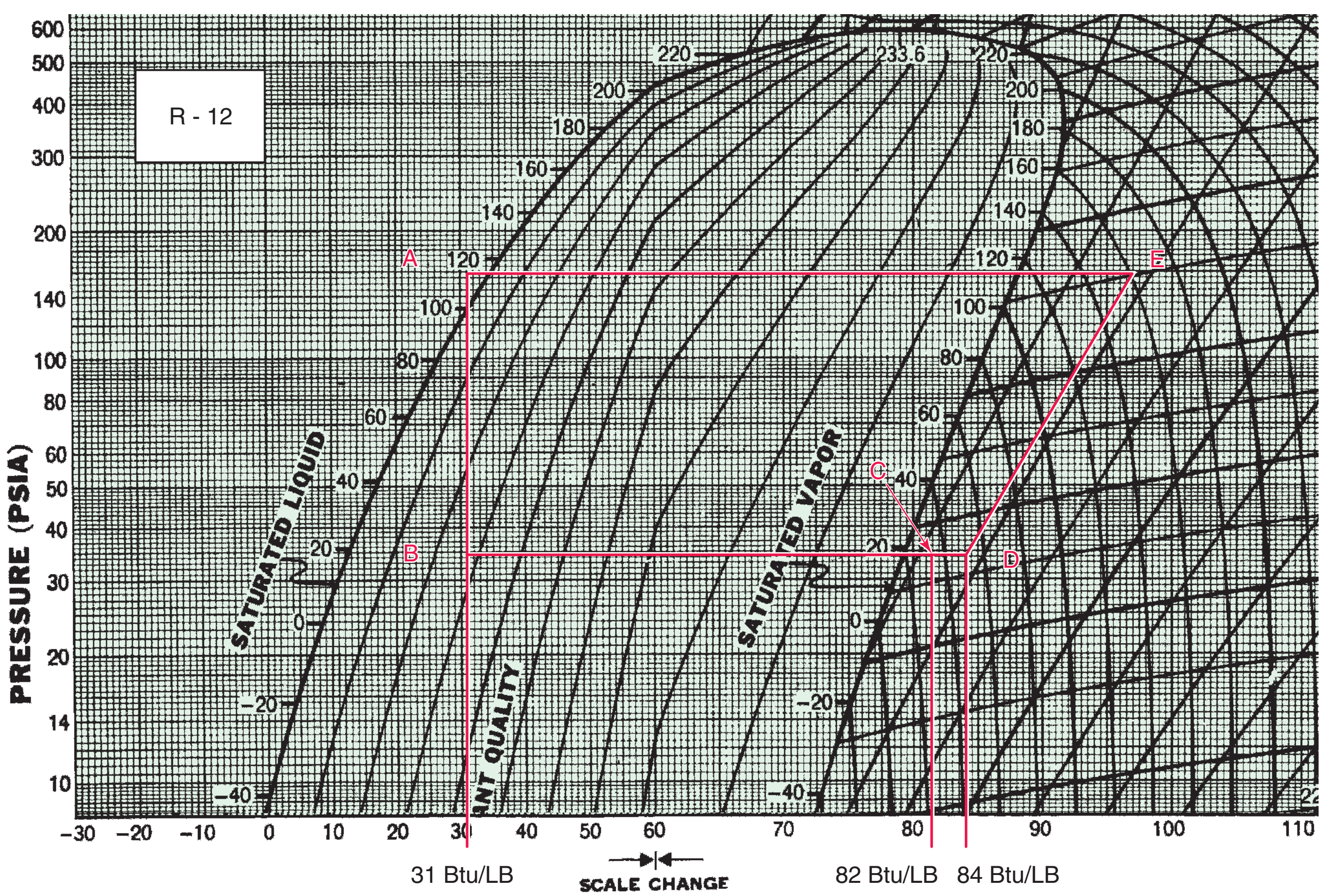


Figure 3–54 An R-12 medium-temperature refrigeration system. *Courtesy E. I. DuPont*

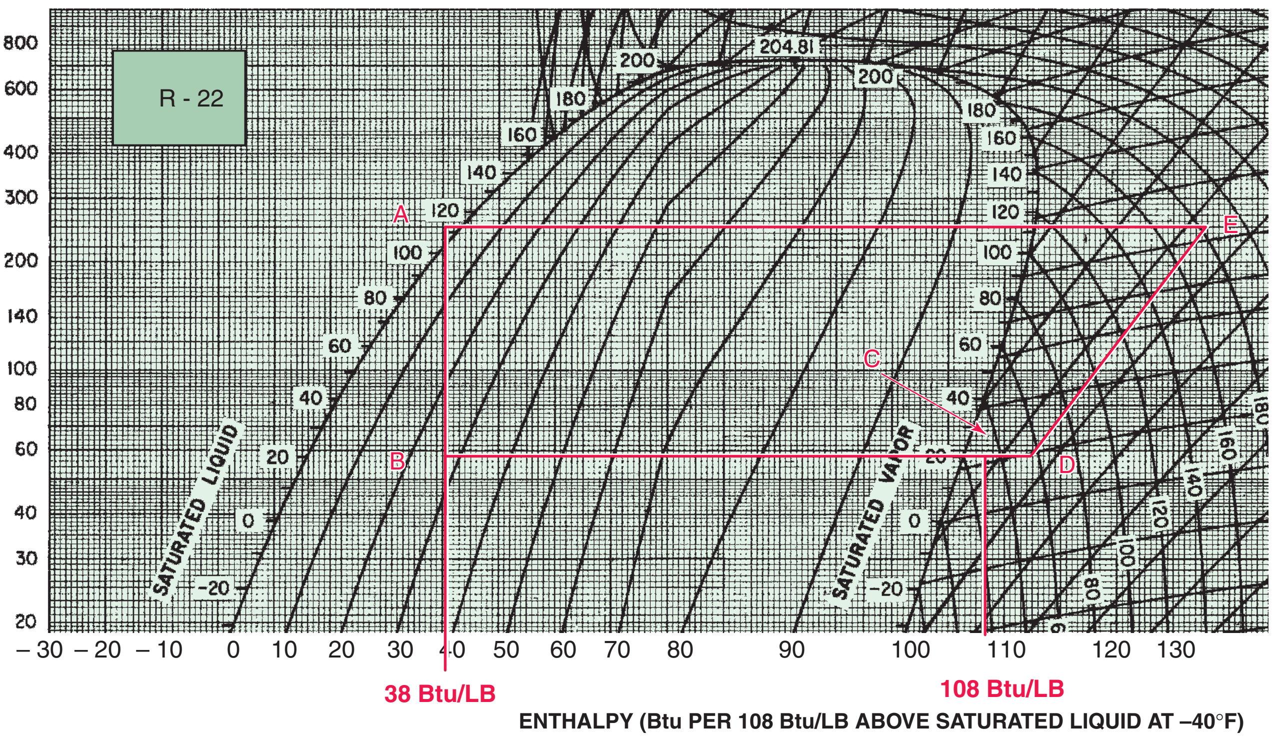


Figure 3–55 An R-22 medium-temperature refrigeration system. *Courtesy E. I. DuPont*

4. Refrigerant vapor enters the compressor at point D at 57°F, containing 37° of superheat. The heat content at the inlet of the compressor, point D, is 113 Btu/lb.
5. The vapor refrigerant is compressed on the line from D to E and leaves the compressor at point E at a temperature of about 180°F. *This is 20°F higher than the temperature for similar conditions for R-12 and is one of the main differences in the refrigerants. R-22 has a much higher discharge temperature than R-12.* As the condensing temperature of the application becomes higher, the temperature rises. At some point, the designer must decide to either use a different refrigerant or change the application.
6. The heat content at the outlet of the compressor, point E, is 136 Btu/lb. Since the refrigerant entered the compressor with a heat content of 113 Btu/lb, the amount of heat added to the refrigerant during the compression process is 23 Btu/lb (136 Btu/lb − 113 Btu/lb). This is referred to as the heat of work (HOW) for the compressor.
7. There was an additional 5 Btu/lb added to the refrigerant in the suction line (113 Btu/lb − 108 Btu/lb). The additional heat added to the system outside of the evaporator is referred to as the heat of compression (HOC) and, in this case, is equal to 28 Btu/lb (23 Btu/lb from the compression process + 5 Btu/lb from the suction line).

R-134a, a replacement refrigerant for R-12, would plot out on the pressure/enthalpy chart as follows. Use **Figure 3–56** to follow this example.

1. Refrigerant enters the expansion valve at point A at 105°F, subcooled 10° from 115°F.
2. Refrigerant leaves the expansion valve at point B with a heat content of 47 Btu/lb. The quality is 33% vapor with 67% liquid. It then travels through the evaporator.
3. Vapor refrigerant leaves the evaporator at point C with a heat content of 109 Btu/lb and a net refrigeration effect of 62 Btu/lb (109 − 47 = 62).
4. The refrigerant enters the compressor at point D with a superheat of 40° and a heat content of 114 Btu/lb. The vapor is compressed along the line from D to E. *Note the lower discharge temperature of 160°F.*
5. The refrigerant leaves the compressor at point E with a heat content of 130 Btu/lb. The HOW for this system is 16 Btu (130 Btu/lb − 114 Btu/lb) and the HOC for this system is 21 Btu/lb [(130 Btu/lb − 114 Btu/lb) + (114 Btu/lb − 109 Btu/lb)]. The HOC can also be determined by subtracting the heat content at point C from the heat content at point E (130 Btu/lb − 109 Btu/lb).
6. The refrigerant is then desuperheated 45°F from point E to the saturated vapor line.
7. The refrigerant is now gradually condensed from the saturated vapor line to the saturated liquid line at 115°F. This is the *latent heat of condensation* being rejected.
8. The saturated liquid is now subcooled from the saturated liquid line to point A. It is subcooled 10° (115°F − 105°F) until it enters the metering device at 105°F. The process then repeats itself.

Another comparison of refrigerants may be made using low temperature as the application. Here we will see much higher discharge temperatures and see why some decisions about various refrigerants are made. We will use a condensing

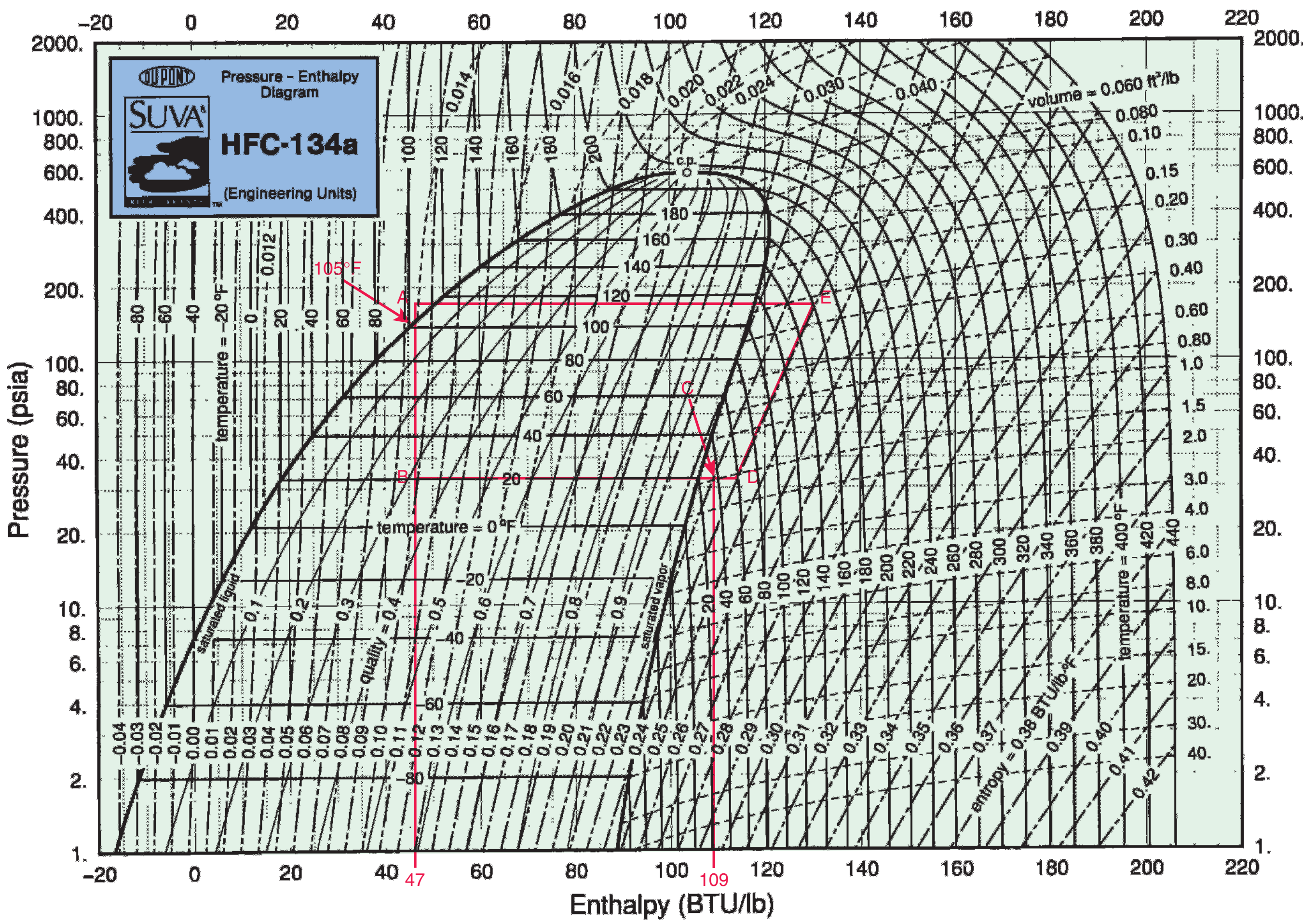


Figure 3–56 An R-134a pressure/enthalpy diagram. *Courtesy E. I. DuPont*

temperature of 115°F and an evaporator temperature of −20°F and compare R-12 to R-502, then to R-22.

Figure 3–57 shows a low-temperature R-12 refrigeration system on a pressure/enthalpy chart. Follow the plot below.

1. The refrigerant enters the expansion valve at point A at 105°F, subcooled 10° from 115°F, like the above examples.
2. The refrigerant leaves the expansion valve at point B at −20°F to be boiled to a vapor in the evaporator. NOTE: The pressure for R-12 boiling at −20°F is 0.6 psig, very close to atmospheric pressure. If the boiling point were any lower, the low side of the system would be in a vacuum. This is one of the disadvantages of R-12 and R-134a as refrigerants for low-temperature application. For this system to maintain a room temperature of about 0°F, the coil temperature can be only 20°F below the return air temperature (0°F room or return air temperature −20°F temperature difference = −20°F coil temperature), **Figure 3–58.** If the thermostat were to be turned down too low, the low-pressure side of this system would be in a vacuum. NOTE: The percentage of liquid to vapor mixture is different for low-temperature than for medium-temperature applications. In this example, we have 39% vapor and 61% liquid leaving the expansion valve. The difference is that extra flash gas is required to lower the remaining liquid to the lower temperature of −20°F. The heat content of the refrigerant at the inlet of the evaporator is 32 Btu/lb.
3. At point C, the refrigerant leaves the evaporator in the vapor state at a temperature of −10°F, with 10° of superheat and a heat content of 76 Btu/lb. The NRE for this evaporator is 44 Btu/lb.
4. The vapor refrigerant enters the compressor at point D with 30° of superheat at a temperature of 10°F and is compressed along the line to point E. The heat content at point D is 78 Btu/lb.
5. Notice that the discharge temperature is only 170°F, a very cool discharge temperature. The refrigerant leaves the compressor at point E with a heat content of 98 Btu/lb. The refrigerant is then desuperheated 55°F from point E to the saturated vapor line. It is left as an exercise to confirm that the HOW for this system is 20 Btu/lb and that the HOC for this system is 22 Btu/lb.
6. The refrigerant is now gradually condensed from the saturated vapor line to the saturated liquid line at 115°F. This is the *latent heat of condensation* being rejected.

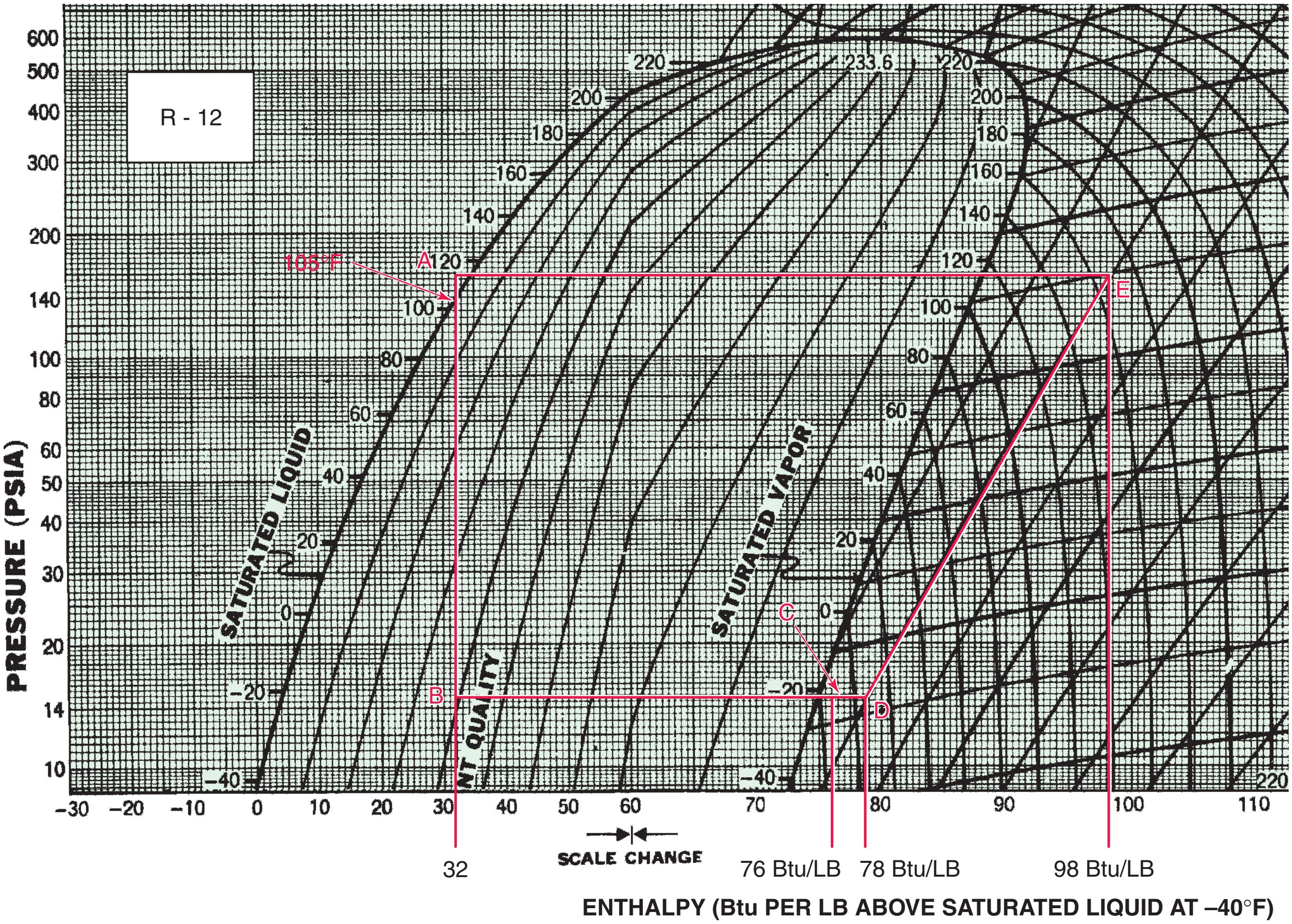


Figure 3–57 An R-12 low-temperature refrigeration system. *Courtesy E. I. DuPont*

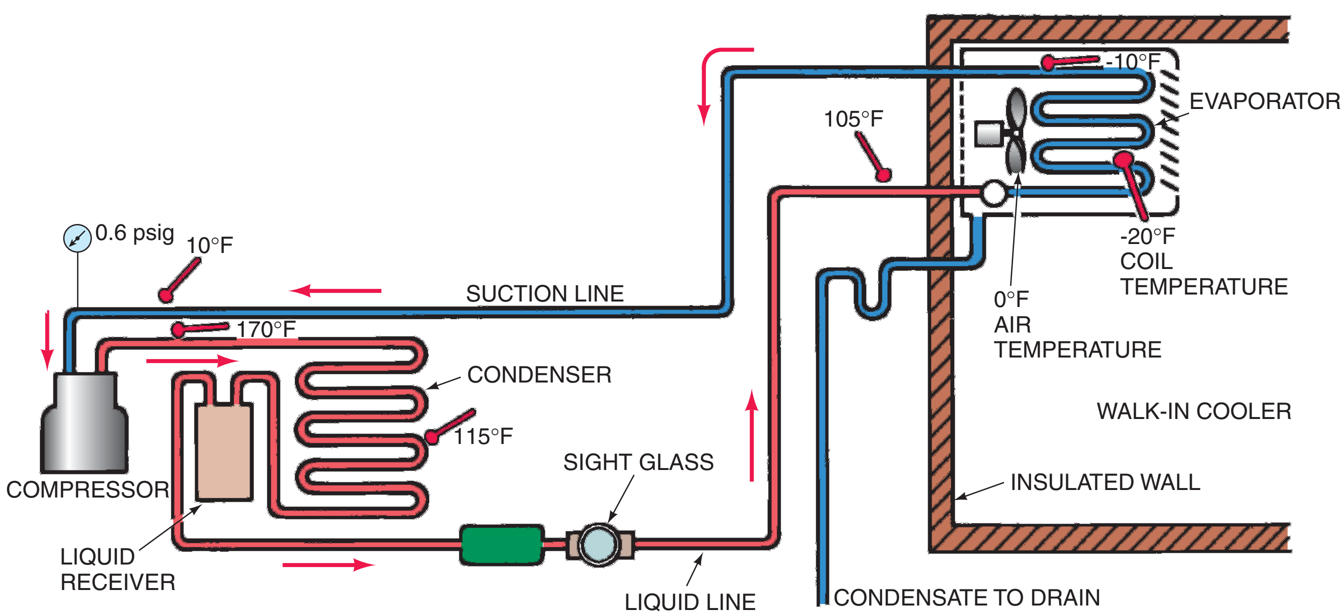


Figure 3–58 The refrigerant is boiling at −20°F. The room air temperature is 0°F.

7. The saturated liquid is now subcooled from the saturated liquid line to point A. It is subcooled 10° (115°F − 105°F) until it enters the metering device at 105°F. The process then repeats itself.

R-502 has been used for many low-temperature applications to prevent the system from operating in a vacuum on the low-pressure side. Follow the same conditions using R-502 in **Figure 3–59.**

1. Refrigerant enters the expansion valve at 105°F, subcooled from 115°F and 48% vapor, 52% liquid. The heat content is 38 Btu/lb.
2. The remaining vapor is evaporated and 10° of superheat is added by the time the vapor reaches point C. The heat content rises to 78 Btu/lb, and the NRE is 40 Btu/lb.
3. The vapor enters the compressor at point D and is compressed to point E where the vapor leaves the compressor at 160°F.
4. The refrigerant is then desuperheated, condensed, and subcooled from point E to A.
5. Notice that the suction pressure is 15.3 psig (30 psia) for R-502 while boiling at −20°F. R-502 will not go into a vacuum until the temperature is −50°F. This refrigerant is very good for low-temperature applications because of this. It also has a very acceptable discharge gas temperature.

As an exercise, verify the following:

- Heat content at the inlet of the compressor is 80 Btu/lb.
- Heat content at the outlet of the compressor is 98 Btu/lb.
- Heat of work, HOW, is 18 Btu/lb.
- Heat of compression, HOC, is 20 Btu/lb.

R-22 is being used for many low-temperature applications because R-502 has been phased out due to the CFC/ozone depletion issue. R-22 has the problem of high discharge gas temperature. **Figure 3–60** shows a plot of the low-temperature application above using R-22. Use the following sequence.

1. The refrigerant enters the expansion valve at point A at 105°F, subcooled from 115°F, just as in the preceding problem. At the inlet of the evaporator, the refrigerant has a heat content of 40 Btu/lb. The refrigerant leaves the evaporator at point C with a heat content of 104 Btu/lb. The temperature at the outlet of the evaporator is −10°F, so the evaporator is operating with 10 degrees of superheat. The NRE for this evaporator is 64 Btu/lb (104 Btu/lb − 40 Btu/lb).
2. The refrigerant is evaporated to a vapor at −20°F and enters the compressor at point D at a temperature of 20°F. Notice that R-22 boils at 10.1 psig at −20°F. It is in a positive pressure. Evaporators using R-22 can be operated down to −41°F before the suction pressure goes into a vacuum. The heat content at the inlet of the compressor is 110 Btu/lb.
3. The vapor is compressed along line D to E where it leaves the compressor at point E at a temperature of 240°F. Remember, R-12 had a discharge temperature of 170°F at the same condition and R-502 a discharge temperature of 160°F. R-22 is much hotter. A 240°F

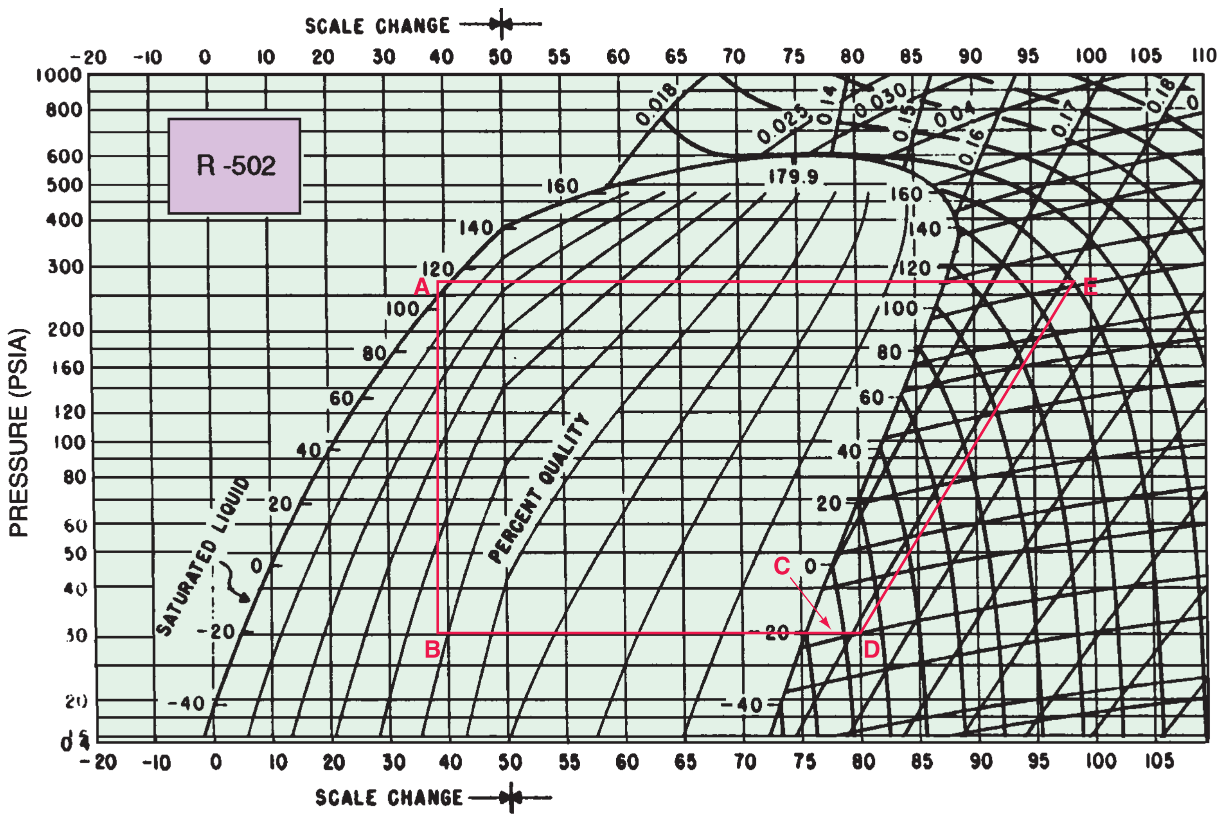


Figure 3–59 An R-502 low-temperature refrigeration system. *Courtesy E. I. DuPont*

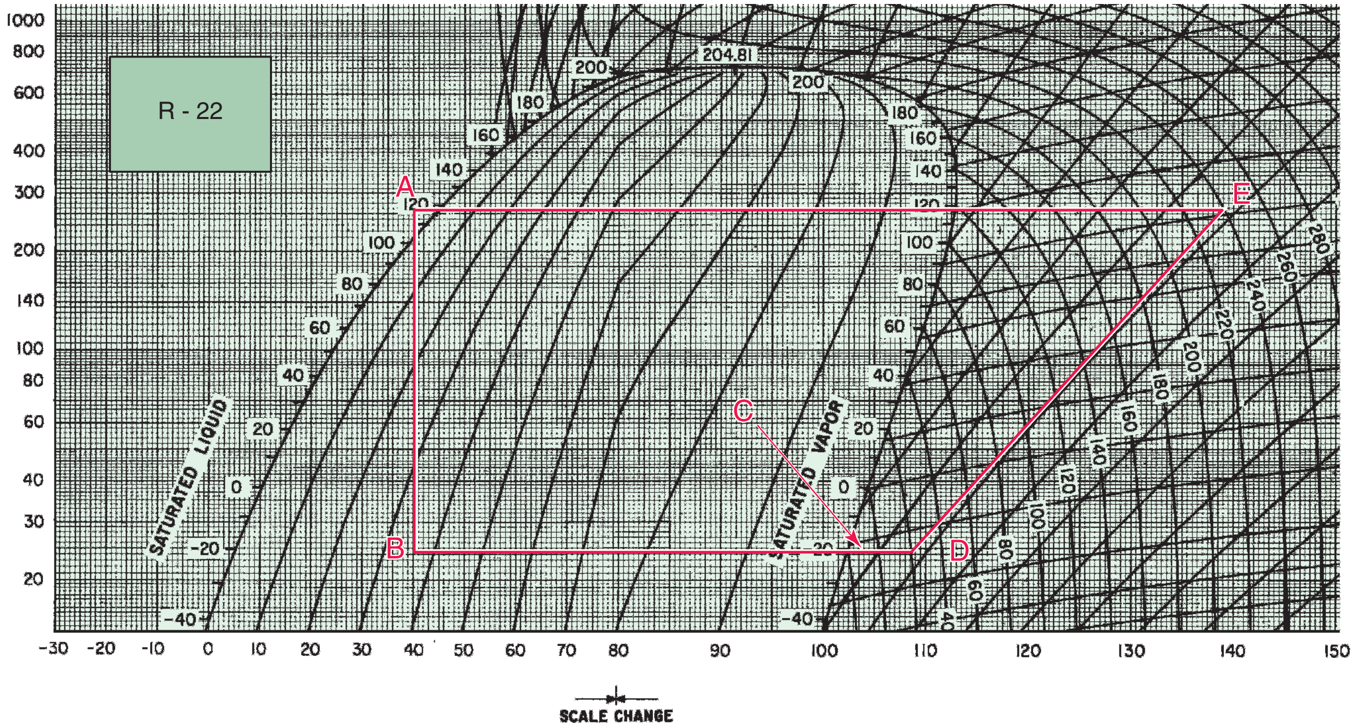


Figure 3–60 An R-22 low-temperature refrigeration system. *Courtesy E. I. DuPont*

discharge temperature can be worked with but is close to being too high. Any increase in discharge temperature due to a dirty condenser can cause serious system problems. The heat content at the outlet of the compressor is 138 Btu/lb, the HOW is 28 Btu/lb, and the HOC is 34 Btu/lb.

4. The vapor leaves the compressor at point E where it is desuperheated, condensed, and subcooled to point A.

As mentioned earlier in this unit, R-22 is subject to phaseout in new equipment in 2010, and total production will be phased out in 2020. A long-term replacement refrigerant for R-22 in new equipment is R-410A. **Figure 3–61** shows an air-conditioning system plotted on a pressure/enthalpy chart incorporating R-410A as the refrigerant. The system is a high-efficiency air-conditioning system operating with a 45°F (130-psig) evaporating temperature and a 115°F (390-psig) condensing temperature. Notice the higher pressures associated with R-410A as compared with an R-22 system. For more detailed information on refrigerants, refer to Unit 9, "Refrigerant and Oil Chemistry and Management—Recovery, Recycling, Reclaiming, and Retrofitting."

Follow the steps below.

1. The refrigerant enters the expansion valve at point A at 105°F, subcooled 10°F from the 115°F condensing temperature.
2. The refrigerant leaves the expansion valve at point B at 45°F (27% vapor and 73% liquid) to be totally evaporated in the evaporator. Because R-410A has such a small temperature glide (0.3°F), it can be ignored in most air-conditioning applications involving pressure/temperature relationships.
3. At point C, the refrigerant leaves the evaporator as 100% vapor with 10°F of evaporator superheat and at a temperature of 55°F. The difference in enthalpy between point B and point C is the net refrigeration effect.
4. The superheated vapor now enters the compressor at point D with 30°F of total superheat and at a temperature of 75°F. The superheated vapor is now compressed along the line to point E to 180°F.
5. The superheated vapor now leaves the compressor at point E. The refrigerant is now desuperheated from point E to the saturated vapor line.
6. The now saturated refrigerant is gradually condensed from the saturated vapor line to the saturated liquid line at 115°F. This is referred to as the latent heat of condensation being rejected.
7. The saturated liquid is now subcooled 10°F (115°F − 105°F) from the saturated liquid line to point A where it enters the metering device at 105°F. The process then repeats itself.

As mentioned earlier, R-502 is used primarily in medium- and low-temperature refrigeration applications. It was banned from manufacturing in 1996. R-502 is an azeotropic refrigerant blend with no temperature glide, and it behaves like a pure compound. R-404A is its long-term replacement refrigerant and has a slightly higher working pressure than R-502. **Figure 3–62** shows a low-temperature refrigeration system plotted on a pressure/enthalpy chart

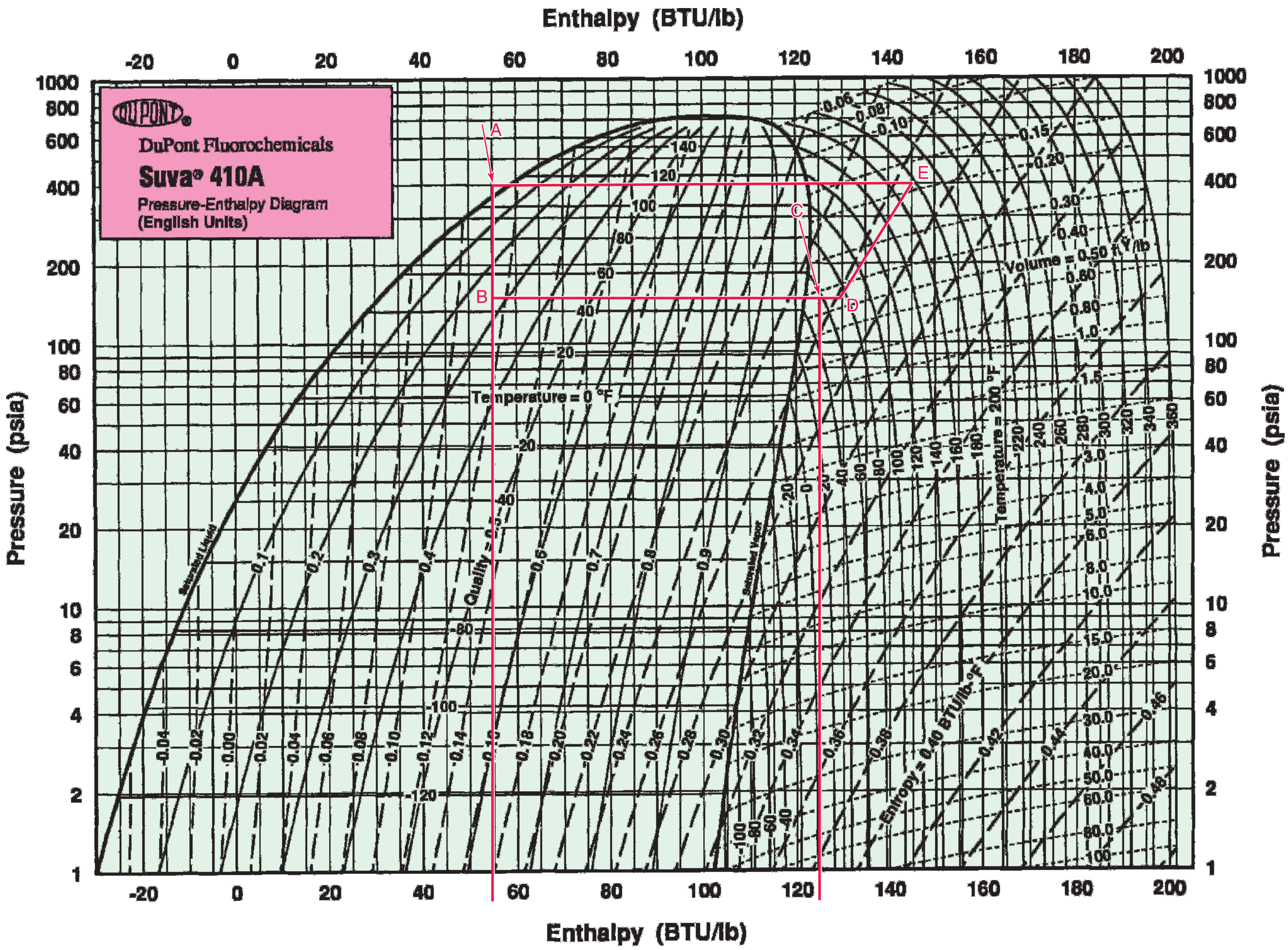


Figure 3–61 An R-410A air-conditioning system. *Courtesy E. I. DuPont*

incorporating R-404A as the refrigerant. The system is a commercial freezer operating with an evaporating temperature of −20°F (16.7-psig) and a 115°F (290-psig) condensing temperature.

Follow the sequence below.

1. The refrigerant enters the expansion valve at point A at 105°F, subcooled 10°F from the 115°F condensing temperature.
2. The refrigerant leaves the expansion valve at point B at −20°F (55% vapor and 45% liquid) to be totally evaporated in the evaporator. At point C, the refrigerant leaves the evaporator as 100% vapor with 10°F of evaporator superheat and at a temperature of −10°F. The difference in enthalpy between point B and point C is the net refrigeration effect.
3. The superheated vapor enters the compressor at point D with 30°F of total superheat and at a temperature of 10°F. The superheated vapor is now compressed along the line to point E to 170°F.
4. The superheated vapor leaves the compressor at point E. The refrigerant is now desuperheated from point E to the saturated vapor line.
5. The now saturated refrigerant is gradually condensed from the saturated vapor line to the saturated liquid line at 115°F. This is referred to as the latent heat of condensation being rejected.
6. The saturated liquid is subcooled 10°F (115°F − 105°F) from the saturated liquid line to point A where it enters the metering device at 105°F. The process then repeats itself.

Pressure/enthalpy diagrams are useful for showing the refrigerant cycle for the purpose of establishing the various conditions around the system. They are partially constructed from properties of refrigerant tables. **Figure 3–63** is a page from a typical table for R-22. Column 1 is the temperature corresponding to the pressure columns for the saturation temperature.

Column 5 lists the specific volume for the saturated vapor refrigerant in cubic feet per pound. For example, at 60°F, the compressor must pump 0.4727 ft^3 of refrigerant to circulate 1 lb of refrigerant in the system. The specific volume along with the net refrigeration effect help the engineer determine the compressor's pumping capacity. The example in **Figure 3–48** using R-22 had a net refrigeration effect of

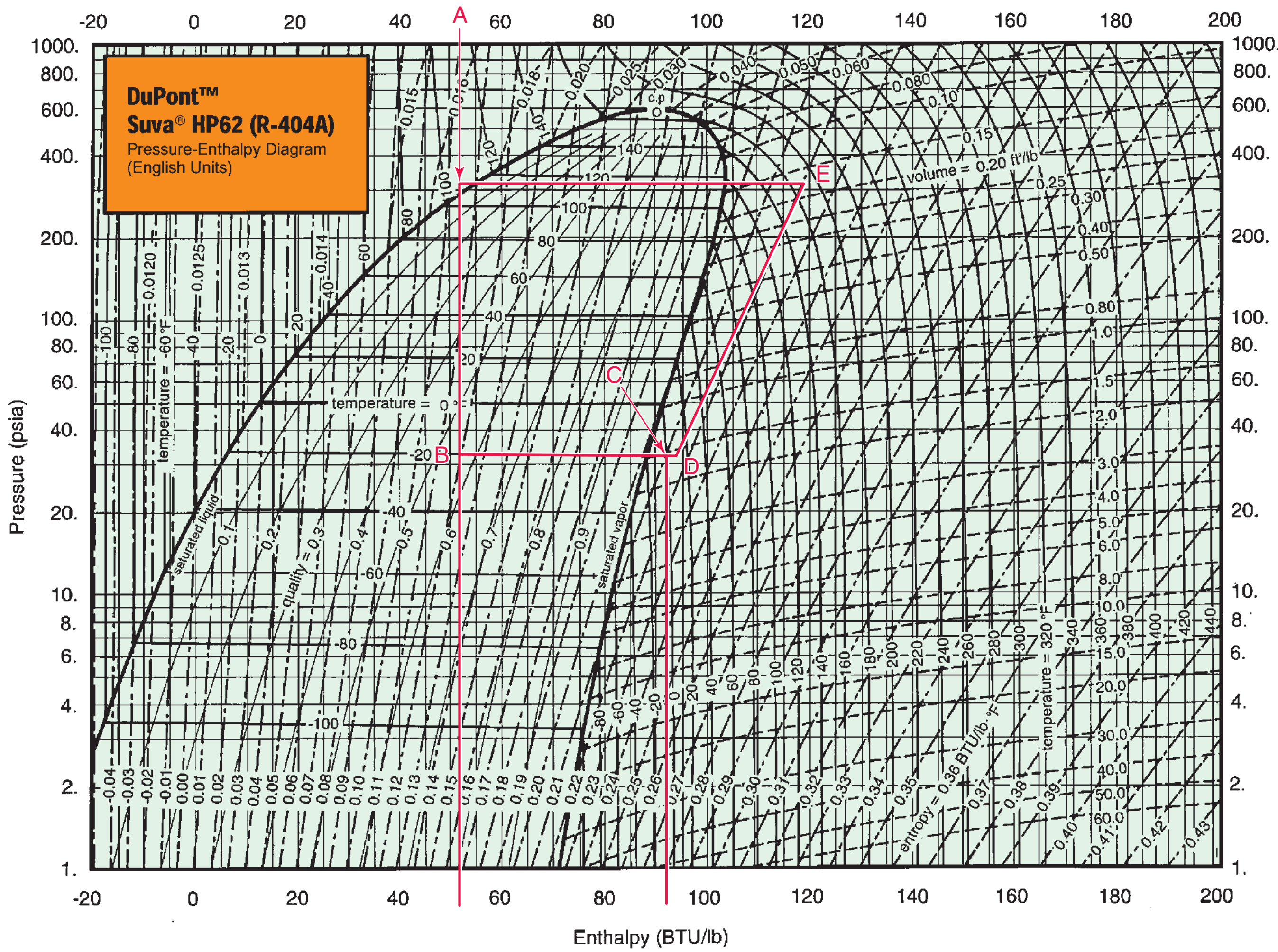


Figure 3–62 An R-404A low-temperature refrigeration system. *Courtesy E. I. DuPont*

61 Btu/lb of refrigeration circulated. If we had a system needing to circulate enough refrigerant to absorb 36,000 Btu/h (3 tons of refrigeration) we would need to circulate 590.2 lb of refrigerant per hour (36,000 Btu/h divided by 61 Btu/lb = 590.2 lb/h). If the refrigerant entered the compressor at 60°F, the compressor must move 275 ft^3 of refrigerant per hour (590.2 lb/h × 0.46523 ft^3/lb = 275 ft^3/h). There is a slight error in this calculation because the 0.46523 ft^3/h is for saturated refrigerant, and the vapor is superheated entering the compressor. Superheat tables are available, but will only complicate this calculation more and there is very little error. Many compressors are rated in cubic feet per minute so this compressor would need to pump 4.58 ft^3/min (275 ft^3/h ÷ 60 min/h = 4.58 ft^3/min).

The density portion of the table tells the engineer how much a particular volume of liquid refrigerant will weigh at the rated temperature. For example, 1 ft^3 of R-22 weighs 76.773 lb when the liquid temperature is 60°F. This is important for determining the weight of refrigerant in components, such as evaporators, condensers, and receivers.

The enthalpy portion of the table (total heat) lists the heat content of the liquid and vapor and the amount of latent heat required to boil 1 lb of liquid to a vapor. For example, at 60°F, saturated liquid refrigerant would contain 27.172 Btu/lb compared with 0 Btu/lb at −40°F. It would require 82.54 Btu/lb to boil 1 lb of 60°F saturated liquid to a vapor. The saturated vapor would then contain 109.712 Btu/lb total heat (27.172 + 82.54 = 109.712).

The entropy column is of no practical value except on the pressure/enthalpy chart where it is used to plot the compressor discharge temperature.

These charts and tables are not normally used in the field for troubleshooting but are for engineers to use to design equipment. They help the technician understand the refrigerants and the refrigerant cycle.

Different refrigerants have different temperature/pressure relationships and enthalpy relationships. These all must be considered by the engineer when choosing the correct refrigerant for a particular application. A complete study of each refrigerant and its comparison to all other refrigerants is helpful, but you do not need to understand the complete picture to successfully perform in the field. A complete study and comparison is beyond the scope of this book.

TEMP.	PRESSURE		VOLUME cu ft/lb		DENSITY lb/cu ft		ENTHALPY Btu/lb			ENTROPY Btu/(lb)(°R)		TEMP.
°F	PSIA	PSIG	LIQUID v_f	VAPOR v_g	LIQUID $1/v_f$	VAPOR $1/v_g$	LIQUID h_f	LATENT h_{fg}	VAPOR h_g	LIQUID s_f	VAPOR s_g	°F
10	47.464	32.768	0.012088	1.1290	82.724	0.88571	13.104	92.338	105.442	0.02932	0.22592	10
11	48.423	33.727	0.012105	1.1077	82.612	0.90275	13.376	92.162	105.538	0.02990	0.22570	11
12	49.396	34.700	0.012121	1.0869	82.501	0.92005	13.648	91.986	105.633	0.03047	0.22548	12
13	50.384	35.688	0.012138	1.0665	82.389	0.93761	13.920	91.808	105.728	0.03104	0.22527	13
14	51.387	36.691	0.012154	1.0466	82.276	0.95544	14.193	91.630	105.823	0.03161	0.22505	14
15	52.405	37.709	0.012171	1.0272	82.164	0.97352	14.466	91.451	105.917	0.03218	0.22484	15
16	53.438	38.742	0.012188	1.0082	82.051	0.99188	14.739	91.272	106.011	0.03275	0.22463	16
17	54.487	39.791	0.012204	0.98961	81.938	1.0105	15.013	91.091	106.105	0.03332	0.22442	17
18	55.551	40.855	0.012221	0.97144	81.825	1.0294	15.288	90.910	106.198	0.03389	0.22421	18
19	56.631	41.935	0.012238	0.95368	81.711	1.0486	15.562	90.728	106.290	0.03446	0.22400	19
20	57.727	43.031	0.012255	0.93631	81.597	1.0680	15.837	90.545	106.383	0.03503	0.22379	20
21	58.839	44.143	0.012273	0.91932	81.483	1.0878	16.113	90.362	106.475	0.03560	0.22358	21
22	59.967	45.271	0.012290	0.90270	81.368	1.1078	16.389	90.178	106.566	0.03617	0.22338	22
23	61.111	46.415	0.012307	0.88645	81.253	1.1281	16.665	89.993	106.657	0.03674	0.22318	23
24	62.272	47.576	0.012325	0.87055	81.138	1.1487	16.942	89.807	106.748	0.03730	0.22297	24
25	63.450	48.754	0.012342	0.85500	81.023	1.1696	17.219	89.620	106.839	0.03787	0.22277	25
26	64.644	49.948	0.012360	0.83978	80.907	1.1908	17.496	89.433	106.928	0.03844	0.22257	26
27	65.855	51.159	0.012378	0.82488	80.791	1.2123	17.774	89.244	107.018	0.03900	0.22237	27
28	67.083	52.387	0.012395	0.81031	80.675	1.2341	18.052	89.055	107.107	0.03958	0.22217	28
29	68.328	53.632	0.012413	0.79604	80.558	1.2562	18.330	88.865	107.196	0.04013	0.22198	29
30	69.591	54.895	0.012431	0.78208	80.441	1.2786	18.609	88.674	107.284	0.04070	0.22178	30
31	70.871	56.175	0.012450	0.76842	80.324	1.3014	18.889	88.483	107.372	0.04126	0.22158	31
32	72.169	57.473	0.012468	0.75503	80.207	1.3244	19.169	88.290	107.459	0.04182	0.22139	32
33	73.485	58.789	0.012486	0.74194	80.089	1.3478	19.449	88.097	107.546	0.04239	0.22119	33
34	74.818	60.122	0.012505	0.72911	79.971	1.3715	19.729	87.903	107.632	0.04295	0.22100	34
35	76.170	61.474	0.012523	0.71655	79.852	1.3956	20.010	87.708	107.719	0.04351	0.22081	35
36	77.540	62.844	0.012542	0.70425	79.733	1.4199	20.292	87.512	107.804	0.04407	0.22062	36
37	78.929	64.233	0.012561	0.69221	79.614	1.4447	20.574	87.316	107.889	0.04464	0.22043	37
38	80.336	65.640	0.012579	0.68041	79.495	1.4697	20.856	87.118	107.974	0.04520	0.22024	38
39	81.761	67.065	0.012598	0.66885	79.375	1.4951	21.138	86.920	108.058	0.04576	0.22005	39
40	83.206	68.510	0.012618	0.65753	79.255	1.5208	21.422	86.720	108.142	0.04632	0.21986	40
41	84.670	69.974	0.012637	0.64643	79.134	1.5469	21.705	86.520	108.225	0.04688	0.21968	41
42	86.153	71.457	0.012656	0.63557	79.013	1.5734	21.989	86.319	108.308	0.04744	0.21949	42
43	87.655	72.959	0.012676	0.62492	78.892	1.6002	22.273	86.117	108.390	0.04800	0.21931	43
44	89.177	74.481	0.012695	0.61448	78.770	1.6274	22.558	85.914	108.472	0.04855	0.21912	44
45	90.719	76.023	0.012715	0.60425	78.648	1.6549	22.843	85.710	108.553	0.04911	0.21894	45
46	92.280	77.584	0.012735	0.59422	78.526	1.6829	23.129	85.506	108.634	0.04967	0.21876	46
47	93.861	79.165	0.012755	0.58440	78.403	1.7112	23.415	85.300	108.715	0.05023	0.21858	47
48	95.463	80.767	0.012775	0.57476	78.280	1.7398	23.701	85.094	108.795	0.05079	0.21839	48
49	97.085	82.389	0.012795	0.56532	78.157	1.7689	23.988	84.886	108.874	0.05134	0.21821	49
50	98.727	84.031	0.012815	0.55606	78.033	1.7984	24.275	84.678	108.953	0.05190	0.21803	50
51	100.39	85.69	0.012836	0.54698	77.909	1.8282	24.563	84.468	109.031	0.05245	0.21785	51
52	102.07	87.38	0.012856	0.53808	77.784	1.8585	24.851	84.258	109.109	0.05301	0.21768	52
53	103.78	89.08	0.012877	0.52934	77.659	1.8891	25.139	84.047	109.186	0.05357	0.21750	53
54	105.50	90.81	0.012898	0.52078	77.534	1.9202	25.429	83.834	109.263	0.05412	0.21732	54
55	107.25	92.56	0.012919	0.51238	77.408	1.9517	25.718	83.621	109.339	0.05468	0.21714	55
56	109.02	94.32	0.012940	0.50414	77.282	1.9836	26.008	83.407	109.415	0.05523	0.21697	56
57	110.81	96.11	0.012961	0.49606	77.155	2.0159	26.298	83.191	109.490	0.05579	0.21679	57
58	112.62	97.93	0.012982	0.48813	77.028	2.0486	26.589	82.975	109.564	0.05634	0.21662	58
59	114.46	99.76	0.013004	0.48035	76.900	2.0818	26.880	82.758	109.638	0.05689	0.21644	59
60	116.31	101.62	0.013025	0.46523	76.773	2.1154	27.172	82.540	109.712	0.05745	0.21627	60
61	118.19	103.49	0.013047	0.46523	76.644	2.1495	27.464	82.320	109.785	0.05800	0.21610	61
62	120.09	105.39	0.013069	0.45788	76.515	2.1840	27.757	82.100	109.857	0.05855	0.21592	62
63	122.01	107.32	0.013091	0.45066	76.386	2.2190	28.050	81.878	109.929	0.05910	0.21575	63
64	123.96	109.26	0.013114	0.44358	76.257	2.2544	28.344	81.656	110.000	0.05966	0.21558	64

Figure 3–63 A portion of the R-22 properties table. *Courtesy E. I. DuPont*

3.21 PLOTTING THE REFRIGERANT CYCLE FOR BLENDS WITH NOTICEABLE TEMPERATURE GLIDE (ZEOTROPIC BLENDS)

Temperature glide occurs when the refrigerant blend has many temperatures as it evaporates or condenses at a given pressure. The pressure/enthalpy diagram for refrigerants with temperature glide differs from that for refrigerants that do not have temperature glide. **Figure 3–64** illustrates a skeletal pressure/enthalpy diagram for a refrigerant blend with temperature glide. Notice that the lines of constant temperature (isotherms) are not horizontal, but are angled downward as they travel from saturated liquid to saturated vapor. As you follow the lines of constant pressure (isobars) straight across from saturated liquid to saturated vapor, more than one isotherm will be intersected. This illustrates that for any one pressure (evaporating or condensing), there will be a range of temperatures associated with it, and the blend is said to have temperature glide. For example, in **Figure 3–64,** for a constant pressure of 130 psia, the temperature glide is 10°F (70°F − 60°F). The isobar of 130 psia intersects both the 60°F and the 70°F isobars as it travels from saturated liquid to saturated vapor.

Figure 3–65 illustrates an actual pressure/enthalpy diagram for refrigerant R-407C, a zeotropic refrigerant blend with very similar properties to R-22 in air-conditioning equipment. It is a blend of R-32, R-125, and R-134a with a fairly large temperature glide (10°F) in the ranges of air-conditioning applications. Notice the isotherms being angled downward from left to right showing temperature glide.

The terms *near-azeotropic* blends and *zeotropic blends* are used interchangeably in the HVACR industry because they both exhibit temperature glide and fractionation. However, zeotropes have temperature glide to a larger extent than near-azeotropic blends. Refer to Unit 9 for more in-depth information on refrigerants, refrigerant blends, temperature glide, and fractionation. Charging methods for refrigerant blends will be covered in Unit 10, "System Charging." SAFETY PRECAUTION: All refrigerants that have been discussed in this text are stored in pressurized containers and should be handled with care. Consult your instructor or supervisor about the use and handling of these refrigerants. Goggles and gloves should be worn while transferring the refrigerants from the container to the system.

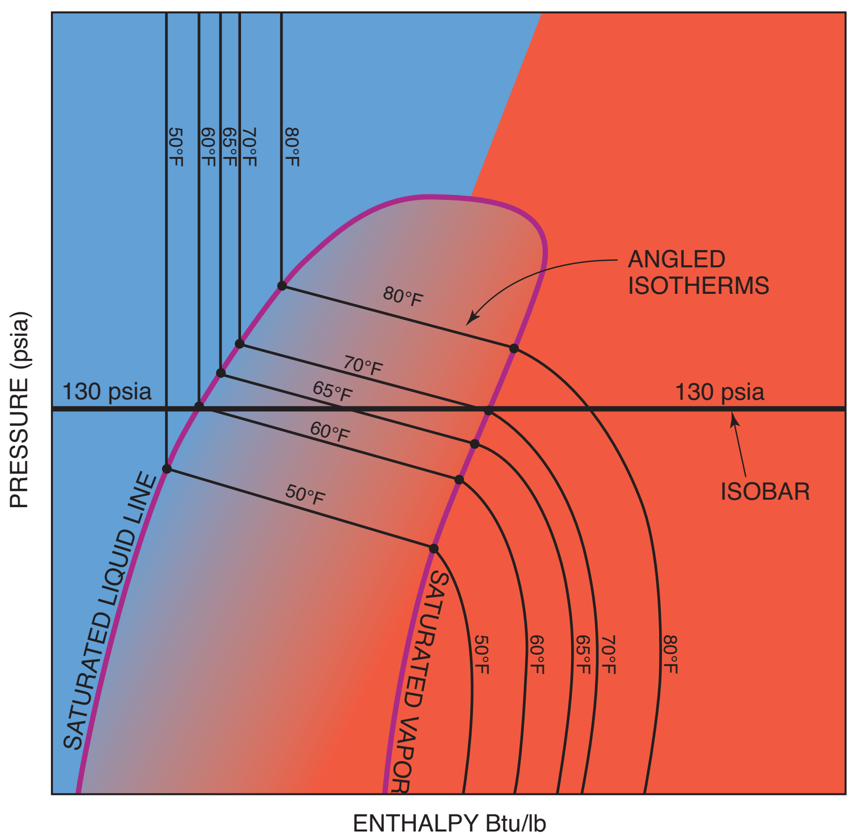


Figure 3–64 A skeletal pressure/enthalpy diagram of a refrigerant blend with a noticeable temperature glide (near-azeotropic blend). Notice the angled isotherms.

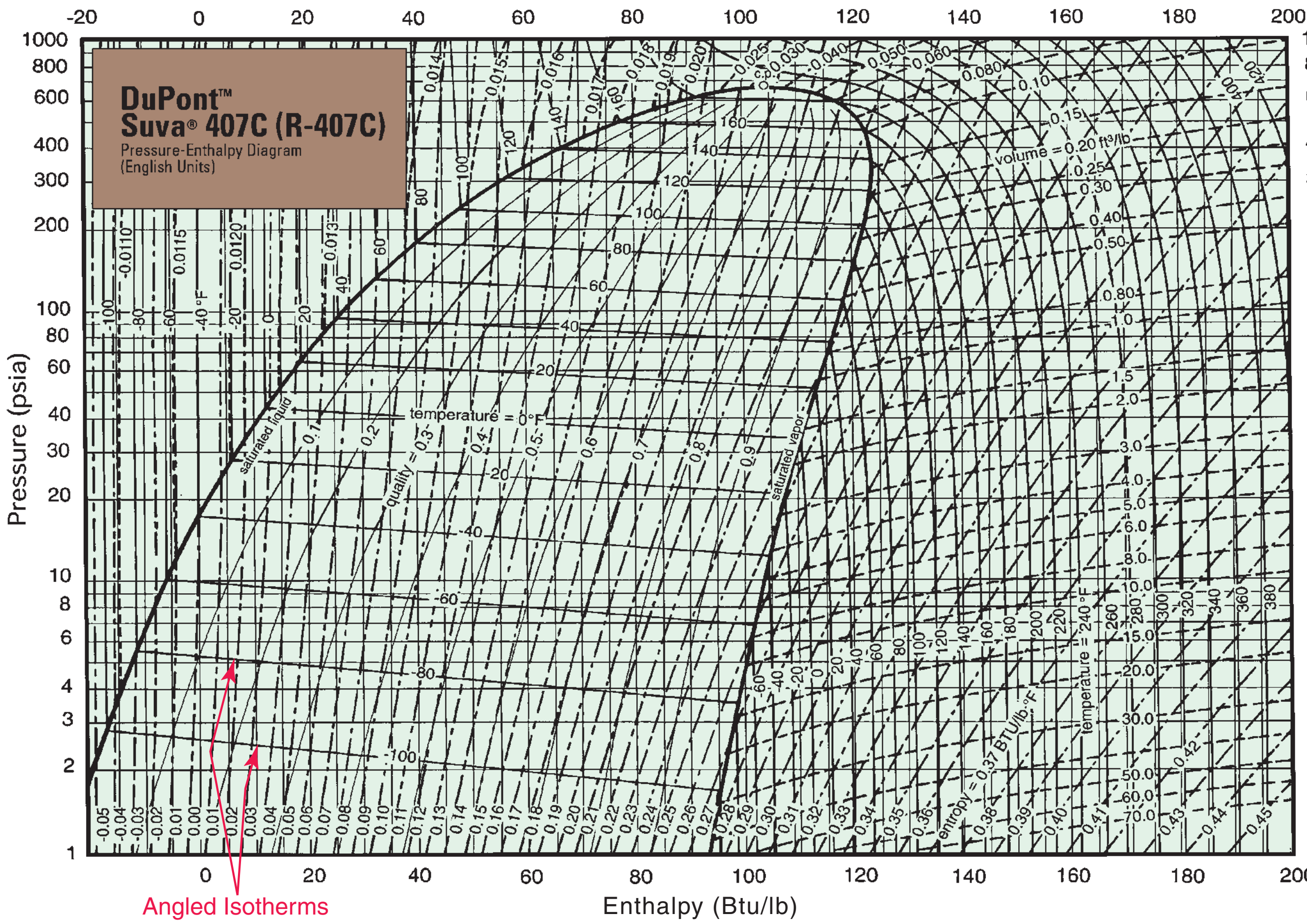


Figure 3–65 A pressure/enthalpy diagram for refrigerant R-407C showing the angled isotherms. *Courtesy E. I. DuPont*

SUMMARY

- Bacterial growth that causes food spoilage slows at low temperatures.
- Product temperatures above 45°F and below room temperature are considered high-temperature refrigeration.
- Product temperatures between 35°F and 45°F are considered medium-temperature refrigeration.
- Product temperatures from 0°F to −10°F are considered low-temperature refrigeration.
- Refrigeration is the process of removing heat from a place where it is not wanted and transferring it to a place where it makes little or no difference.
- One ton of refrigeration is the amount of heat necessary to melt 1 ton of ice in a 24-hour period. It takes 288,000 Btu to melt 1 ton of ice in a 24-hour period or 12,000 Btu in 1 h or 200 Btu in 1 min.
- The relationship of the vapor pressure and the boiling point temperature is called the temperature/pressure relationship.
- A compressor can be considered a vapor pump. It lowers the pressure in the evaporator to the desired temperature and increases the pressure in the condenser to a level where the vapor may be condensed to a liquid.
- The liquid refrigerant moves from the condenser to the metering device where it again enters the evaporator.
- Refrigerants have a definite chemical makeup and are usually designated with an “R” and a number for field identification.
- A refrigerant must be safe, must be detectable, must be environmentally friendly, must have a low boiling point, and must have good pumping characteristics.
- Refrigerant cylinders are color coded to indicate the type of refrigerant they contain.
- Refrigerants should be recovered or stored while a refrigeration system is being serviced, then recycled, if appropriate, or sent to a manufacturer to be reclaimed.
- Pressure/enthalpy diagrams may be used to plot refrigeration cycles.

REVIEW QUESTIONS

1. Name three reasons why ice melts in an icebox: _________, _________, _________.
2. What are the approximate temperature ranges for low-, medium-, and high-temperature refrigeration applications?
3. One ton of refrigeration is
   A. 1200 Btu.
   B. 12,000 Btu/h.
   C. 120,000 Btu.
   D. 120,000 Btu/h.

4. Describe briefly the basic refrigeration cycle.
5. What is the relationship between pressure and the boiling point of liquids?
6. What is the function of the evaporator in a refrigeration or air-conditioning system?
7. What does the compressor do in the refrigeration system?
8. Define a superheated vapor.
9. The evaporating pressure is 76 psig for R-22, and the evaporator outlet temperature is 58°F. What is the evaporator superheat for this system?
A. 13°F
B. 74°F
C. 18°F
D. 17°F
10. If the evaporating pressure was 76 psig for R-22 and the compressor inlet temperature was 65°F, what would be the total superheat entering the compressor?
A. 11°F
B. 21°F
C. 10°F
D. 20°F
11. Define a subcooled liquid.
12. The condensing pressure is 260 psig, and the condenser outlet temperature is 108°F for R-22. By how many degrees is the liquid subcooled in the condenser?
A. 12°F
B. 42°F
C. 7°F
D. 14°F
13. The condensing pressure is 260 psig, and the metering device inlet temperature is 100°F for R-22. What is the total subcooling in this system?
A. 15°F
B. 20°F
C. 25°F
D. 30°F
14. What is meant by a saturated liquid and vapor?
15. What is meant by desuperheating a vapor?
16. What happens to the refrigerant in the condenser?
17. What happens to refrigerant heat in the condenser?
18. The metering device
A. cycles the compressor.
B. controls subcooling.
C. stores refrigerant.
D. meters refrigerant.
19. What is adiabatic expansion?
20. Describe flash gas and tell how it affects system capacity.
21. Quality means _______ when referring to a refrigerant.
22. Describe the difference between a reciprocating compressor and a rotary compressor.
23. List the cylinder color codes for R-12, R-22, R-502, R-134a, R-11, R-401A, R-402B, R-410A, R-404A, and R-407C.
24. Define enthalpy.
25. Define a pure compound refrigerant and give two examples.
26. Define net refrigeration effect as it applies to the refrigeration cycle.
27. Define heat of work and explain how it is computed.
28. Define heat of compression and explain how it is computed.
29. Explain the relationship between HOW and HOC.
30. Define flash gas and explain how it applies to the net refrigeration effect of the refrigeration cycle.
31. Define temperature glide as it pertains to a refrigerant blend.
32. Define a zeotropic refrigerant blend and give an example.
33. Define a near-azeotropic refrigerant blend and give two examples.